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Industrial QUALITY CONTROL

Vol. XV, No. 3
September, 1958

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Evaluating Vendor Quality Conformance

Statistics in the Chemical Industry

Tolerances for Mating Parts

Gaging of Large Dimensions or Small Tolerances

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Measure in Millionths

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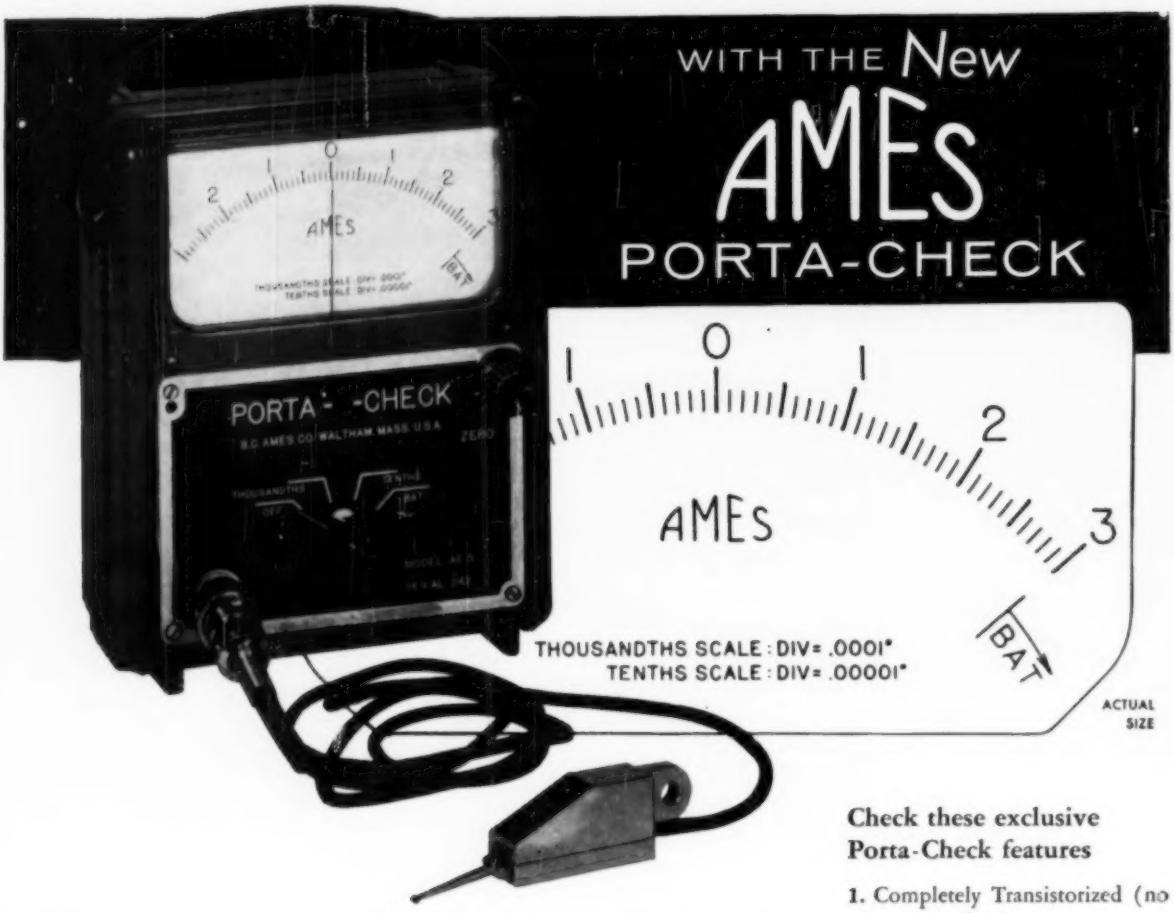

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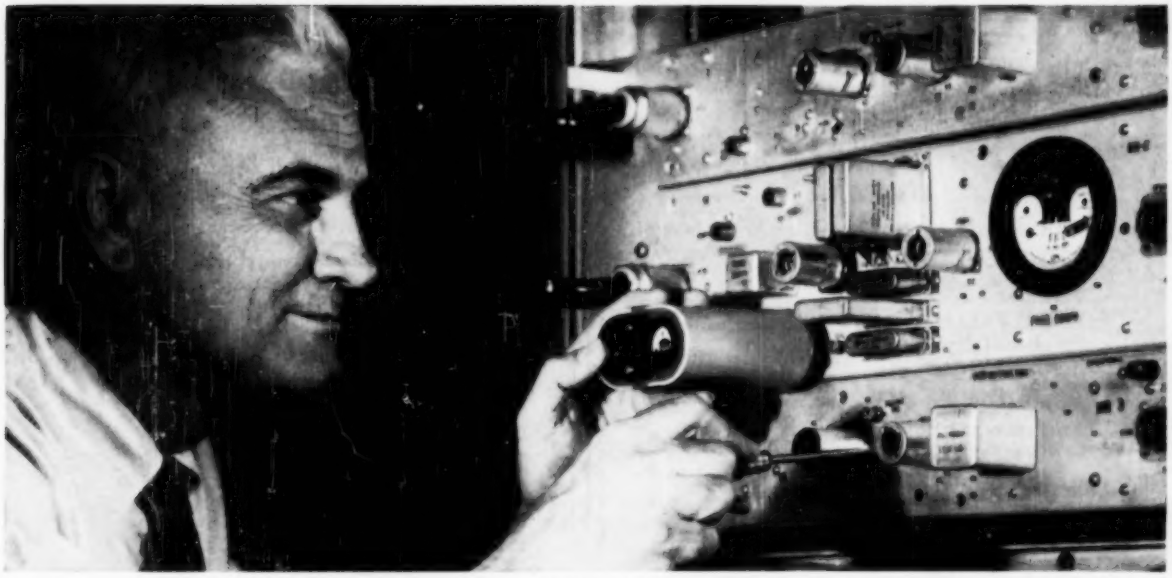
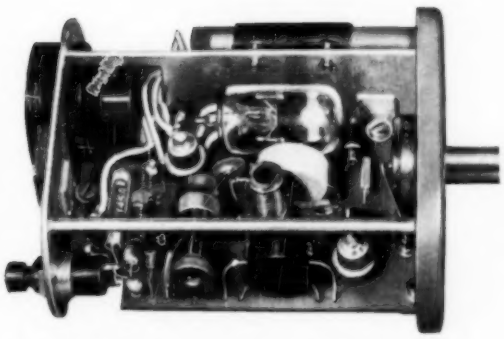
Bell Laboratories Announces Pocket-Sized Frequency Standard for Microwave Systems



Lawrence Koerner, who developed the portable frequency standard, demonstrates how the device can be plugged in at a radio relay station to supply a checking frequency. Battery-powered, the device maintains precision calibration for several months.



Inside the portable frequency standard. Four Laboratories-developed devices make it possible: (1) transistor, which converts the power from a battery to radio frequency oscillations; (2) voltage reference diode, which maintains constant voltage; (3) piezoelectric crystal unit of superlative stability; (4) thermistor, which corrects for temperature variations.

Microwave radio relay systems depend critically on the accuracy of their "carrier" frequencies. At scores of relay stations along a route, carrier frequency oscillators must be checked periodically against a signal from a precise standard.

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Until now, such precision in a frequency standard has been obtainable only in a laboratory. The new portable standard makes it available for routine use in the Bell System. First use of the standard will be to maintain frequency control in a new microwave system for telephone and TV, now under development at Bell Laboratories.

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Vol. XV, No. 3 **September, 1958**

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Industrial Quality Control is published monthly by the American Society for Quality Control, Inc. Entered as second-class matter on Sept. 18, 1950 at the post office at Milwaukee, Wis.

Industrial Quality Control is sent to all members of the Society as one of the privileges of membership; yearly subscription is $3.00 of the membership dues. Subscriptions from non-members are not accepted. Subscriptions for company, public, and university libraries are: 1 yr.—$9.00; 2 yrs.—$17.00; 3 yrs.—$25.00; 5 yrs.—$40.00. Back issues of Vols. I-X are available at $6.00 per volume including index; Vol. XI, $9.00; XII-XIII-XIV, $10.00 ea. Individual copies are $1.00 each. Microfilm editions by volume are also available. The cost per volume is I-VII, $10.00; VIII, $1.50; IX, X, $1.60 ea.; XI, $1.70; XII, $1.85; XIII, $2.00.

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Industrial Quality Control is regularly indexed in the *APPLIED SCIENCE & TECHNOLOGY INDEX* published by The H. W. Wilson Company, 930 University Avenue, New York 52, N. Y.

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Executive Secretary and Publications office: Rm. 6197 Plankinton Bldg., 161 West Wisconsin Avenue, Milwaukee 3, Wisconsin. Society's New York Address: Rm. 965, 463 West St., New York 14, N. Y.

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Determining Testing Efficiency

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Introduction

The purpose of this article is to present a simple, straightforward procedure for determining the "testing-efficiency" of a specific inspection routine. As used in this article, **"testing-efficiency" (hereinafter referred to as E) is the probability that a defective unit will be recognized as such during an inspection.** The probability that a good unit will be mistakenly identified as a defective is assumed to be either zero or so small that it can be neglected. Moreover, "inspection routine" designates a specific operator, test equipment and inspection item.

Determining E

The procedure for determining E is by repeat testing. We start by making several basic assumptions, as follows:

1. During an inspection, not all the defective units are found, but, on the average, E percent of the defective units are found and eliminated. Further, for any specific inspection routine E is assumed to be a constant.
2. No good unit is ever judged defective.
3. Repeated inspection creates no defectives.

On the basis of these assumptions, we proceed as follows:

1. Let E = testing efficiency (a constant).
2. Let N_x = total number of units in the sample at the start of the x^{th} test.
3. Let G = number of good units in the sample (a constant).
4. Let y_x = fraction found bad during x^{th} test.
5. Let B_x = fraction actually defective at start of x^{th} test.

Then:

$$N_2 = N_1(1 - y_1) \tag{1}$$

also

$$N_3 = N_2(1 - y_2) = N_1(1 - y_1)(1 - y_2) \tag{2}$$

and in general,

$$N_x = N_1(1 - y_1)(1 - y_2) \ldots (1 - y_{x-1}) \tag{3}$$

Stated differently,

$$N_{x+1} = N_x(1 - y_x) \tag{4}$$

The number of good units in the sample is

$$G = N_x\left(1 - \frac{y_x}{E}\right) \tag{5}$$

Since G is independent of x, we may write

$$G = N_x\left(1 - \frac{y_x}{E}\right) = N_{x+1}\left(1 - \frac{y_{x+1}}{E}\right) \tag{6}$$

and eliminating N_{x+1} by (4), one obtains

$$1 - \frac{y_x}{E} = (1 - y_x)\left(1 - \frac{y_{x+1}}{E}\right) \tag{7}$$

Solving for E,

$$E = 1 - \frac{y_{x+1}}{y_x}(1 - y_x) \tag{8}$$

Thus, by performing only two inspections, one can estimate E. (In actual practice, of course, E will be subject to a certain amount of statistical fluctuation; therefore, before making a practical application of E, it would be necessary to determine an average E from the results of a series of repeat inspections.)

Once E is known, one can determine the fraction of actually defective units in the sample by the simple relationship

$$B_x = \frac{y_x}{E} \tag{9}$$

Similarly, one can predict the results of future inspections of the same sample by solving for y_{x+1} in (8). Thus

$$y_{x+1} = \frac{y_x(1 - E)}{(1 - y_x)} \tag{10}$$

By dividing (10) through by E, one obtains an expression which will yield the fraction of actually defective units *left* in the sample after the x^{th} test. Thus

$$\frac{y_{x+1}}{E} = \frac{y_x(1 - E)}{E(1 - y_x)} = B_{x+1} \tag{11}$$

Equations (10) and (11), of course, may be extended as far as is desired. Thus

$$y_{x+2} = \frac{y_x(1 - E)^2}{1 - y_x - y_x(1 - E)} \tag{12}$$

and

$$\frac{y_{x+2}}{E} = \frac{1}{E}\left[\frac{y_x(1 - E)^2}{1 - y_x - y_x(1 - E)}\right] = B_{x+2} \tag{13}$$

The relationships (8) through (13) enable one to determine the following:

1. The testing efficiency (E).
2. The fraction of actually defective units in the sample [from (9)].
3. The fraction of defective units expected to be found in the sample on subsequent inspections [from (10) and (12)].
4. The fraction of actually defective units left in the sample after the x^{th} inspection [from (11) and (13)].

It should be noted that the relationships shown in (8) through (13) apply to the sample. Two of these, y_x and B_x, are sample statistics subject to sampling variation, therefore these relationships must be treated the same as any other sample statistics when it comes to estimating lot parameters.

Graphical Solution For E and B_x

To facilitate the use of the equations developed above, graphical solutions are provided on Figures 1 and 2. These graphs are designed to yield values of E and B_x when y_x and y_{x+1} are known, but it is readily apparent that they may be entered with any two of the variables to obtain solutions for the remaining two. Figure 2 is merely an enlargement of that portion of Fig. 1 which covers a practical range of y_x and y_{x+1}.

The Meaning of a Constant Fraction Defective

From Fig. 1, it may be observed that two rather interesting relationships hold true when the fraction found defective remains constant from inspection to inspection. The first of these is that then the testing efficiency is equal to the fraction found defective (i.e., when $y_1 = y_2 = \ldots = y_n$, then $E = y_1 = y_2 = \ldots = y_n$. This may be clearly seen from (8). Secondly, the entire sample is actually defective (i.e., when $y_1 = y_2 = \ldots = y_n$, then $B = 1.0$). This is evident if the first relationship is

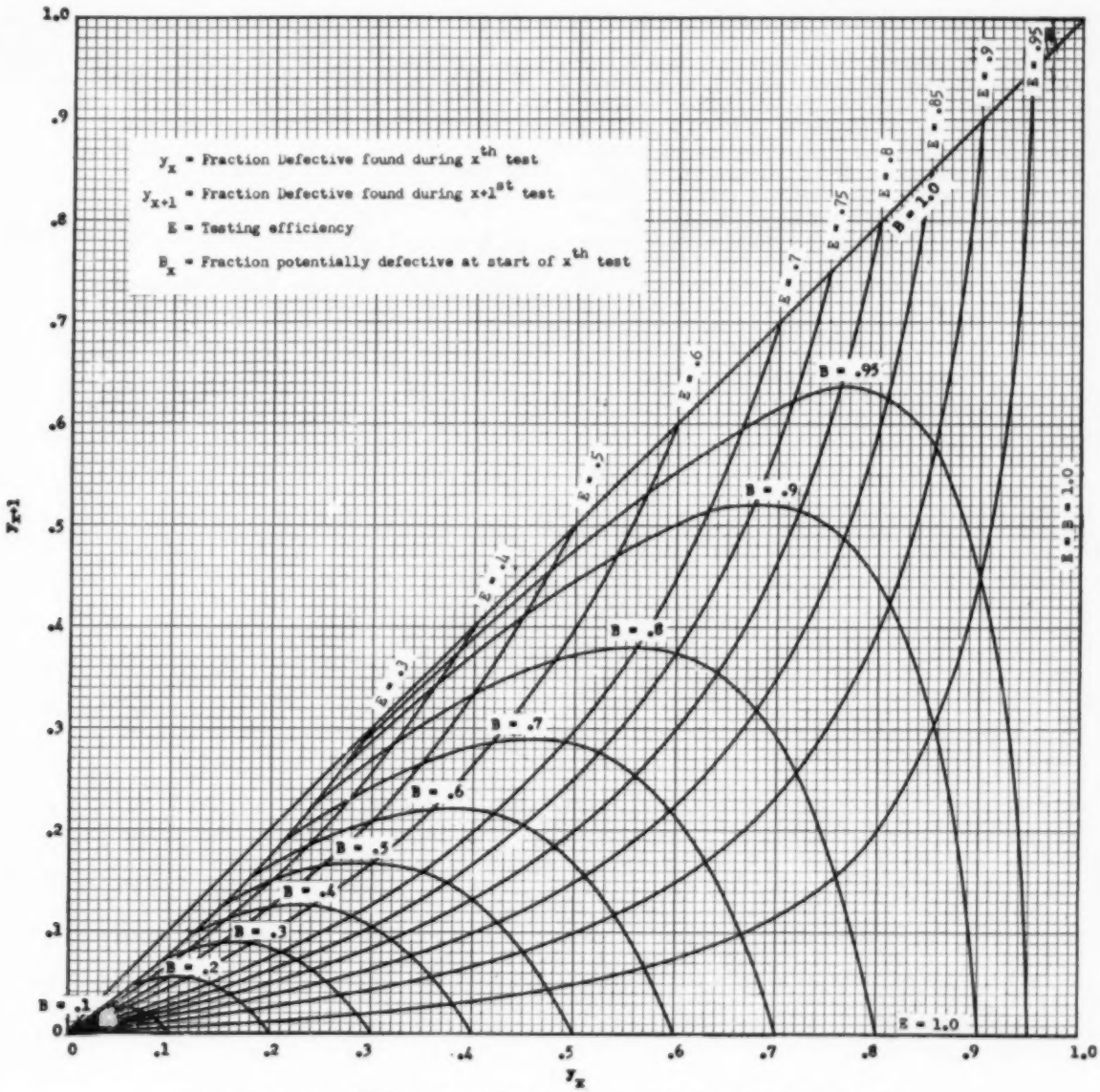

Figure 1—Graphical Solution for E and B_x, Given y_x and y_{x+1} ($0 \leq y_x \leq 1$, $0 \leq y_{x+1} \leq 1$)

applied to (9). The second relationship is also evident from a purely logical standpoint if one reasons that each subsequent inspection has done nothing to improve the fraction defective in the remainder of the sample. Clearly, if during each inspection one finds the same fraction defective, the sample will eventually be exhausted [see equation (3)].

As a further illustration of the second relationship, consider the case in which $y_1 = y_2 = 0.5$. From Fig. 1, E also equals 0.5, therefore, one expects to find (on the first inspection) half the defectives contained in the sample. If, then, half the sample is found to be defective during the first inspection, obviously the remaining half is also defective. Of course, if small samples are involved the above relationships will occasionally yield nonsensical answers since y_x and y_{x+1} are then very limited discrete values, and subject to wide statistical fluctuations. For this reason, the samples used in applying the above relationships must be sufficiently large to minimize or largely eliminate statistical variation.

Statistical Fluctuation of E

Although the assumption has been made that E is a constant for a specific inspection routine, it should be understood that this assumption applies to the "average" value of E, hereinafter referred to as E'. If a series of repeat inspections are performed with a specific inspection routine, E will obviously vary (around E') from inspection to inspection. This becomes clear if we consider the results obtained when a large sample (known to contain defects) is re-inspected many times with one inspection routine, and with the defectives found during each inspection being returned to the sample before each subsequent inspection. We know from experience that the same fraction defective will not be found during every inspection. The "true" fraction defective, however, is constant from inspection to inspection (defectives found were replaced), therefore the only explanation for the variation in the "found" fraction defective is a variation in E.

Because E varies, causing y_x and y_{x+1} to vary from their true values, our estimate of E' is not precise. To determine the precision with which E' can be determined, consider the change in E when y_x and y_{x+1} acquire, respectively, the increments Δy_x and Δy_{x+1}.

Since y_x and y_{x+1} vary statistically and independently, the total change in E is

$$\Delta E = \sqrt{\left(\frac{\partial E}{\partial y_x}\right)^2 (\Delta y_x)^2 + \left(\frac{\partial E}{\partial y_{x+1}}\right)^2 (\Delta y_{x+1})^2} \qquad (14)$$

Determining $\frac{\partial E}{\partial y_x}$ and $\frac{\partial E}{\partial y_{x+1}}$ from (8) and substituting the results in (14), one obtains

$$\Delta E = \sqrt{\frac{(y_{x+1})^2}{y_x^4}(\Delta y_x)^2 + \frac{(1 - y_x)^2}{y_x^2}(\Delta y_{x+1})^2} \qquad (15)$$

which may be re-written as

$$\frac{\Delta E}{E} = \frac{1}{E y_x}\sqrt{(y_{x+1})^2\left(\frac{\Delta y_x}{y_x}\right)^2 + (1 - y_x)^2 (y_{x+1})^2\left(\frac{\Delta y_{x+1}}{y_{x+1}}\right)^2} \qquad (16)$$

which expresses the total relative change in E.

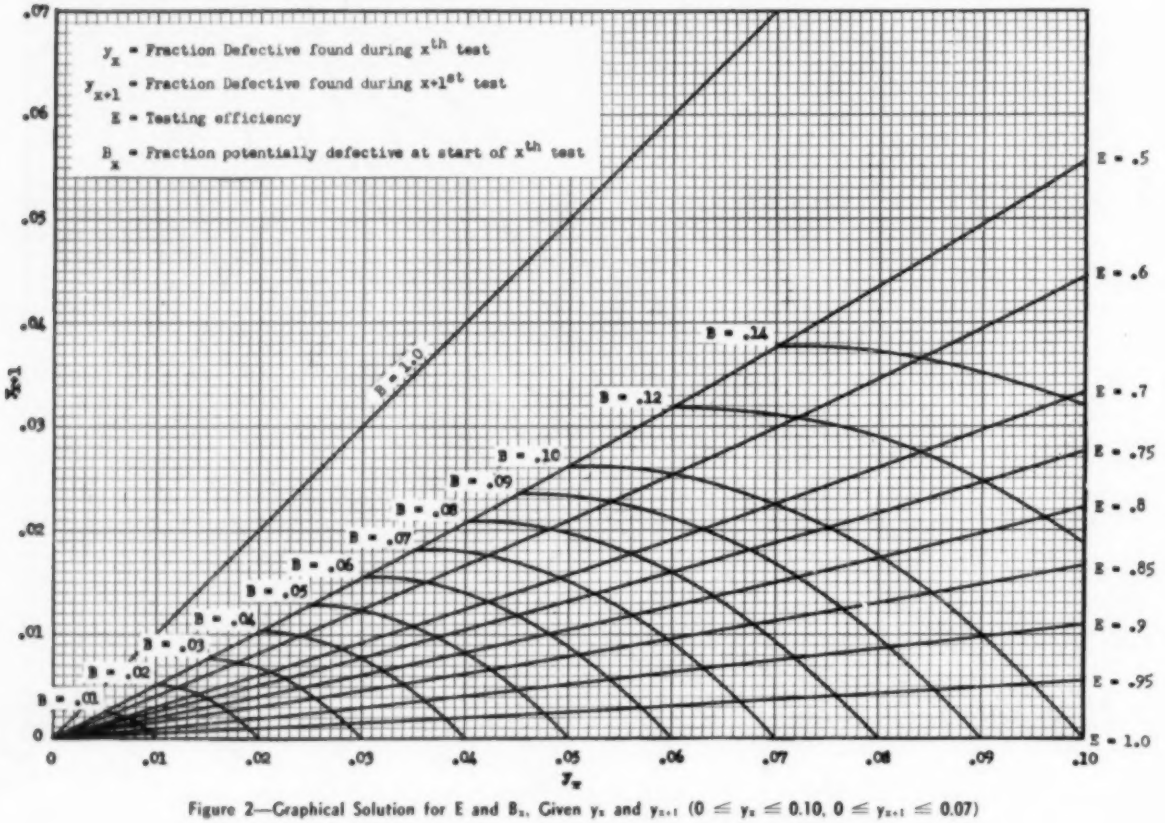

Figure 2—Graphical Solution for E and B_x, Given y_x and y_{x+1} ($0 \leq y_x \leq 0.10$, $0 \leq y_{x+1} \leq 0.07$)

From the discussion in the first paragraph of this section, it is quite clear that $\frac{\Delta y_x}{y_x}$ and $\frac{\Delta y_{x+1}}{y_{x+1}}$ will have in general the same value. Therefore, for simplicity, let $\frac{\Delta y_x}{y_x} = \frac{\Delta y_{x+1}}{y_{x+1}} = \frac{\Delta y}{y}$. We may then write (16) as

$$\frac{\Delta E}{E} = \frac{y_{x+1}}{E y_x}\sqrt{1 + (1 - y_x)^2}\left(\frac{\Delta y}{y}\right) \qquad (17)$$

Replacing E by (8), one obtains

$$\frac{\Delta E}{E} = \frac{y_{x+1}}{y_x - y_{x+1} + y_x\,(y_{x+1})}\sqrt{1 + (1 - y_x)^2}\left(\frac{\Delta y}{y}\right) \qquad (18)$$

which is the exact expression for $\frac{\Delta E}{E}$ assuming

$$\frac{\Delta y_x}{y_x} = \frac{\Delta y_{x+1}}{y_{x+1}} = \frac{\Delta y}{y}.$$

In most practical cases, y_x and hence y_{x+1} have values of 0.05 or less. We can therefore assume y_x and y_{x+1} small as compared to 1 and $y_x\,(y_{x+1})$ small as compared to either y_x or y_{x+1}. We may then write (18) as

$$\frac{\Delta E}{E} = \frac{\sqrt{2}\,y_{x+1}}{y_x - y_{x+1}}\left(\frac{\Delta y}{y}\right) \qquad (19)$$

or

$$\frac{\Delta E}{E} = \frac{\sqrt{2}}{(y_x/y_{x+1}) - 1}\left(\frac{\Delta y}{y}\right). \qquad (20)$$

The difficulty in determining E′ with precision when $\frac{y_x}{y_{x+1}} \longrightarrow 1$ is clearly shown in (20). For example, if y_x and y_{x+1} are known within ± 5 percent, E′ is known within ±14 percent if $\frac{y_x}{y_{x+1}} = 1.5$, but only within ±71 percent if $\frac{y_x}{y_{x+1}} = 1.1$! On the other hand, (20) reveals that when $\frac{y_x}{y_{x+1}} \geq \sqrt{2} + 1$, $\frac{\Delta E}{E} \leq \frac{\Delta y}{y}$; that is, when $\frac{y_x}{y_{x+1}} > 2.4$, E′ [> 0.6 from (8)] can be determined with greater precision than y can be determined.

It is clear from the above discussion that to determine the precision of the estimate of E′, the precision of the estimate of y must be determined. One way this may be found is by re-inspecting a large sample many times, returning the defectives to the sample before each re-inspection. From the standard deviation of the resulting distribution of y's any one of several well-known statistical methods may be used to compute $\frac{\Delta y}{y}$.

Once $\frac{\Delta y}{y}$ is known, (20) may be used to determine confidence limits on E′. It is obvious that where $\frac{y_x}{y_{x+1}}$ is close to 1, $\frac{\Delta y}{y}$ should be made small by using large samples, thus increasing the precision of E′.

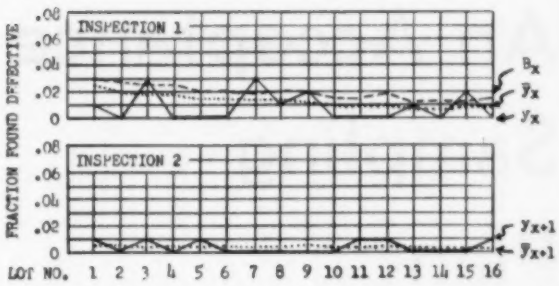

Figure 3—Chart Depicting Results of First and Second Inspections on 16 lots (n_1=100)

Illustrative Application

To illustrate one of the more obvious applications, let us consider an example. Electron tubes are susceptible to several kinds of defects of a non-repetitive nature, with perhaps the most important of these being short circuits. Since so many shorts are non-repetitive, inspecting for them on a straightforward sampling basis leaves something to be desired, as we know in advance that it is extremely unlikely that all of the defectives contained in the sample will be found during any one inspection.

The way this problem was approached was to conduct the sampling on a repetitive basis. That is, the sample was inspected once and all the shorts found were eliminated; the balance of the sample was then reinspected. The fraction defective found during each inspection was recorded in chart form as shown in Fig. 3.

The solid lines in the charts of Fig. 3 indicate the fraction found defective during inspection. The dotted lines indicate the sliding average of the fraction defective in the last 10 samples (in this case, each initial sample consists of 100 tubes, therefore the sliding average is based on the last 1000 tubes inspected).

From the fraction defective sliding averages, we may enter Fig. 2 and obtain B, the fraction actually defective at the start of the 1st test. Values of B are plotted on the top chart as a dashed line. To enter Fig. 2, the fraction defective sliding average of inspection 1 ($\bar{y}_x$) is taken as y_x and the fraction defective sliding average of inspection 2 ($\bar{y}_{x+1}$) is taken as y_{x+1}. From the top chart of Fig. 3, it is quite evident that the true process average (B) is considerably higher than that indicated by the first inspection sampling results.

As a matter of interest, when the above application was first instituted repeat testing was carried through a third inspection. It was soon discovered, however, that with the relationships heretofore developed the results of the third inspection could be accurately predicted from the results of the first and second inspections. Consequently, the only useful purpose of the third inspection was to serve as a check on the validity of the assumptions made in "Determining E." As soon as sufficient third inspection data were available to definitely bear out these assumptions, the third inspection was abandoned.

Acknowledgment

The writer wishes to express his appreciation to Dr. A. K. Wright, Vice President-Director of Engineering, Tung-Sol Electric, Inc., for his valuable contributions to both the organization and content of this article, particularly with respect to the mathematical developments which were originated and developed by him.

An Acceptance Sampling Plan

based on the distribution of the range when sampling from a triangular population

B. OSTLE and J. M. WIESEN

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Abstract

The distribution of the range of a sample of n from a right triangle population is expressed in terms of the range of the population. This is applied to an acceptance sampling problem in which the sample range is the characteristic of importance. The effect of double inspection—not double sampling—is considered. Numerical values are given for samples of 10 and 20.

Introduction

In the purchase of a certain type of cold cathode tube, one of the acceptance tests concerns itself with the jitter of the tube. Jitter is defined as the anode delay-time variation measured by the range of n observations; that is, the longest delay time minus the shortest delay time.

To express the problem in more familiar terms, consider a process which produces delay times. Then each tube may be considered as one lot of delay times—a very large lot. When n delay times are measured on one specific tube, we are, in essence, inspecting a sample of n from a particular lot. The sample range of the n observed delay times gives a measure of the badness of the lot, or tube. This is analogous to the idea in ordinary inspection that the number of defectives in the sample gives an estimate of the badness of the lot. If the range, R, of delay times for a particular tube is greater than an acceptance value, A, the tube will be rejected.

Distribution of Delay Times

An examination of data indicates that the distribution of delay times over many shots on a single tube is triangular in form. Specifically, the distribution appears to be as shown in Fig. 1. In such a case, $f(x)$ is given by

$$f(x) = 2(x-a)/r^2, \quad a \leq x \leq a + r \qquad (1)$$

$$= 0 \quad , \text{ elsewhere.}$$

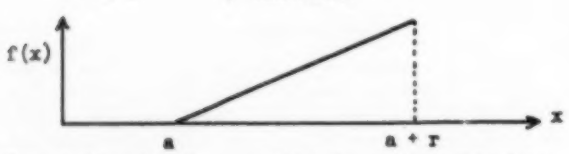

Figure 1—Theoretical Frequency Distribution of Anode Delay Times for Repeated Shots on a Single Tube (x = anode delay time)

Acceptance Test Procedure

The acceptance test used states that a tube will be accepted if R, the sample range, is less than some specified value, A. It is of interest, therefore, to investigate the probability of acceptance as a function of A and r where r is the population (or lot) range.

It is clear that if $r \leq A$, the tube will be accepted, assuming no errors of inspection. That is, if the ratio of the true range of the tube to the acceptance value is less than or equal to one, the tube will be accepted. If, on the other hand, $\alpha = r/A$ is greater than one, the tube should be rejected. The preceding is, of course, a restatement of the concept of an ideal OC function. In what follows, the probability of accepting a tube when the true range is greater than A has been determined. OC curves are presented in Fig. 2 for $n = 10$ and $n = 20$.

Distribution of the Sample Range

Beginning with the population specified by equation (1), it may be shown that the joint distribution of the largest and smallest values in a sample of n is

$$h(u,v) = n(n-1)\, f(u)\, f(v) \left\{F(v) - F(u)\right\}^{n-2}$$

$$= 4n(n-1)\, (u-a)\, (v-a) \left\{(v-a)^2 - (u-a)^2\right\}^{n-2}/r^{2n} \qquad (2)$$

where u is the smallest sample value, v is the largest sample value and $a \leq u \leq v \leq a + r$. Letting $u = v - R$

TABLE I—Probability of Acceptance when Sampling from a Triangular Distribution: Acceptance is Specified when $R \leq A$

$\alpha = r/A$	Probability of Acceptance	
	n = 10	n = 20
1.0	1.000	1.000
1.1	0.969	0.908
1.2	0.859	0.664
1.3	0.710	0.423
1.4	0.562	0.247
1.5	0.434	0.138
1.6	0.330	0.075
1.7	0.248	0.040
1.8	0.186	0.021
1.9	0.140	0.011
2.0	0.105	0.006
2.1	0.079	
2.2	0.060	
2.3	0.046	
2.4	0.035	
2.5	0.027	
2.6	0.021	
2.7	0.016	
2.8	0.013	
2.9	0.010	
3.0	0.008	

TABLE II(a)—Probability of Acceptance (P_a) Based on Tests at Both the Producer and the Consumer
$n = 10$ for the producer, $n = 10$ for the consumer

α for producer \ α for consumer	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
1.0	1.000	0.969	0.859	0.710	0.563	0.434	0.330	0.248	0.186	0.140	0.105	0.079	0.060	0.046	0.035	0.027	0.021	0.016	0.013	0.010	0.008
1.1	0.969	0.939	0.832	0.688	0.545	0.421	0.319	0.240	0.180	0.135	0.102	0.077	0.058	0.044	0.034	0.026	0.020	0.016	0.012	0.010	0.008
1.2	0.859	0.832	0.737	0.610	0.483	0.373	0.283	0.213	0.160	0.120	0.090	0.068	0.051	0.039	0.030	0.023	0.018	0.014	0.011	0.008	0.007
1.3	0.710	0.688	0.610	0.505	0.400	0.308	0.234	0.176	0.132	0.099	0.075	0.056	0.043	0.032	0.025	0.019	0.015	0.011	0.009	0.007	0.006
1.4	0.562	0.545	0.483	0.400	0.316	0.244	0.185	0.140	0.105	0.079	0.059	0.044	0.034	0.026	0.020	0.015	0.012	0.009	0.007	0.006	0.004
1.5	0.434	0.421	0.373	0.308	0.244	0.188	0.143	0.108	0.081	0.061	0.046	0.034	0.026	0.020	0.015	0.012	0.009	0.007	0.005	0.004	0.003
1.6	0.330	0.319	0.283	0.234	0.185	0.143	0.109	0.082	0.061	0.046	0.035	0.026	0.020	0.015	0.011	0.009	0.007	0.005	0.004	0.003	0.003
1.7	0.248	0.240	0.213	0.176	0.140	0.108	0.082	0.062	0.046	0.035	0.026	0.020	0.015	0.011	0.009	0.007	0.005	0.004	0.003	0.002	0.002
1.8	0.186	0.180	0.160	0.132	0.105	0.081	0.061	0.046	0.035	0.026	0.020	0.015	0.011	0.008	0.006	0.005	0.004	0.003	0.002	0.002	0.001
1.9	0.140	0.135	0.120	0.099	0.079	0.061	0.046	0.035	0.026	0.020	0.015	0.011	0.008	0.006	0.005	0.004	0.003	0.002	0.002	0.001	0.001
2.0	0.105	0.102	0.090	0.075	0.059	0.046	0.035	0.026	0.020	0.015	0.011	0.008	0.006	0.005	0.004	0.003	0.002	0.002	0.001	0.001	0.001
2.1	0.079	0.077	0.068	0.056	0.044	0.034	0.026	0.020	0.015	0.011	0.008	0.006	0.005	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001
2.2	0.060	0.058	0.051	0.043	0.034	0.026	0.020	0.015	0.011	0.008	0.006	0.005	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0
2.3	0.046	0.044	0.039	0.032	0.026	0.020	0.015	0.011	0.008	0.006	0.005	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0	
2.4	0.035	0.034	0.030	0.025	0.020	0.015	0.011	0.009	0.006	0.005	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0		
2.5	0.027	0.026	0.023	0.019	0.015	0.012	0.009	0.007	0.005	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0			
2.6	0.021	0.020	0.018	0.015	0.012	0.009	0.007	0.005	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0				
2.7	0.016	0.016	0.014	0.011	0.009	0.007	0.005	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0					
2.8	0.013	0.012	0.011	0.009	0.007	0.005	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0						
2.9	0.010	0.010	0.008	0.007	0.006	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0							
3.0	0.008	0.008	0.007	0.006	0.004	0.003	0.003	0.002	0.001	0.001	0.001	0.001	0								

and using repeated integration by parts, the sampling distribution of R is obtained, namely,

$$g(R) = \frac{4n(n-1)}{r^{2n}} \int_{a+R}^{a+r} (v-a-R)\,(v-a) \left\{(v-a)^2 - (v-a-R)^2\right\}^{n-2} dv$$

$$= \frac{2nR^{n-2}}{r^{2n}} \left\{ r(r-R)\,(2r-R)^{n-1} - \frac{(2r-R)^{n+1}}{2(n+1)} + \frac{R^{n+1}}{2(n+1)} \right\}$$

$$= \frac{n(n-1)R^{n-2}}{2r^{2n}} \left\{ \frac{(2r-R)^{n+1}}{n+1} - \frac{R^2(2r-R)^{n-1}}{n-1} + \frac{2R^{n+1}}{n^2-1} \right\} \quad (3)$$

where $0 \leq R \leq r$.

OC Function

The probability of acceptance of a tube, P_a, or the OC function, is

$$P_a = P(R \leq A) = P(R \leq r/\alpha). \quad (4)$$

For $\alpha \leq 1$, $P_a = 1$. However, if $\alpha > 1$,

$$P_a = \frac{1 + n(2\alpha-1)^{n+1} + (n+1)\,(2\alpha-1)^n}{2(n+1)\,\alpha^{2n}} \quad (5)$$

Values of P_a are given in Table I for $n = 10$, 20 and for certain selected values of α. The OC curves are shown in Fig. 2.

Double Inspection

Sometimes the product may be sampled both by the producer (prior to shipment) and by the consumer (prior to use). It is of interest to compute the probability of acceptance under such a program. For the following combinations of sample sizes: (1) $n = 10$ at the producer, $n = 10$ at the consumer and (2) $n = 20$ at the producer, $n = 10$ at the consumer, and for various combinations of α—that is, different values of α for the producer and consumer—this has been done. The results are presented in Table II.

TABLE II(b)
$n = 20$ for the producer, $n = 10$ for the consumer

α for producer \ α for consumer	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
1.0	1.000	0.908	0.664	0.423	0.247	0.138	0.075	0.040	0.021	0.011	0.006
1.1	0.908	0.825	0.603	0.384	0.224	0.125	0.068	0.036	0.019	0.010	0.006
1.2	0.664	0.603	0.441	0.281	0.164	0.091	0.050	0.027	0.014	0.008	0.004
1.3	0.423	0.384	0.281	0.179	0.104	0.058	0.032	0.017	0.009	0.005	0.003
1.4	0.247	0.224	0.164	0.104	0.061	0.034	0.018	0.010	0.005	0.003	0.002
1.5	0.138	0.125	0.091	0.058	0.034	0.019	0.010	0.006	0.003	0.002	0.001
1.6	0.075	0.068	0.050	0.032	0.018	0.010	0.006	0.003	0.002	0.001	0
1.7	0.040	0.036	0.027	0.017	0.010	0.006	0.003	0.002	0.001	0	
1.8	0.021	0.019	0.014	0.009	0.005	0.003	0.002	0.001	0		
1.9	0.011	0.010	0.008	0.005	0.003	0.002	0.001	0			
2.0	0.006	0.006	0.004	0.003	0.002	0.001	0				

An examination of Table II, coupled with some information about acceptable values of r and costs of inspection, should provide a means of selecting a reasonable inspection program.

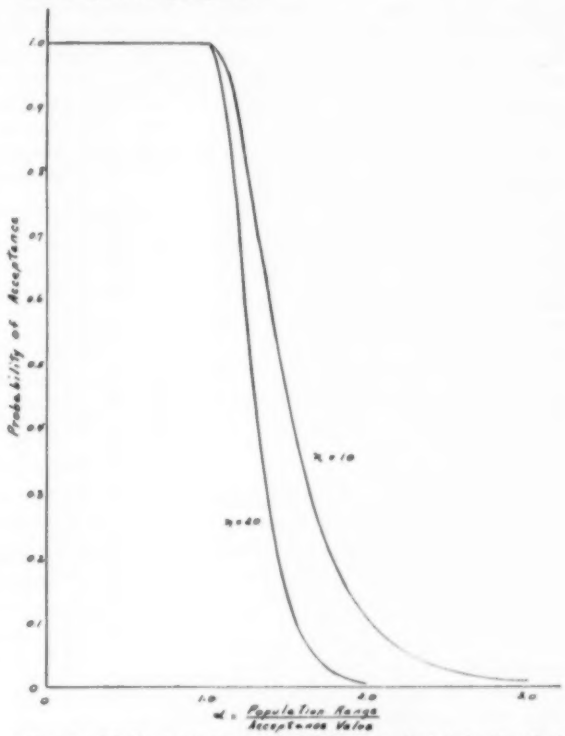

Figure 2—OC Curves for $n = 10$, 20 Associated with the Specified Acceptance Test Procedure

A Vendor Quality Conformance Procedure

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Most companies are selective in choosing suppliers for their respective commodities. In recent years several procedures for accomplishing this have been proposed. Probably the most common of these evaluation procedures involves the construction of a statistic we may call "t" which is then referred to a normal probability scale to yield a vendor conformance index on some associated rating scale. This method of determining conformance measures the amount of deviation the quality of an incoming lot of commodity has from a predetermined quality standard set for this part, and permits probability statements to be made concerning the significance of the deviation of the found quality from the expected quality. Although this procedure has much merit, it has been our experience that it is not generally well understood. The prime purpose of this article is to recast this procedure for judging quality conformance in what we believe to be a simplified form.

The benefits of a formal vendor quality conformance procedure are well demonstrated in our records. We have maintained graphs of the ratios of the number of rejected shipments to the total number of shipments in an evaluation period. We have also kept plots of the ratio of the number of shipments accepted on an off-specification basis to the total number of shipments. These graphs have been kept up for a long period of time as is illustrated in Fig. 1.

The effect of this vendor quality conformance procedure is quite evident and is, we believe, primarily attributable to the procedure we have developed. The classifying of a product's quality serves as a means of bringing to light troublesome areas. It has caused action to be taken to determine the reason. This has resulted in better communications and better relations with our vendors. When we first started, 35.4 percent of our vendors fell into an unacceptable category. This procedure, as a tool, helped reduce this percentage to 14.2 percent.

It may be noticed that reference is made to the procedure as "Vendor Quality Conformance." This is very intentional. When we first formalized the procedure, we called it "Vendor Rating." This is quite a misnomer. The title "Vendor Rating" has the connotation of the personal. In order to avoid this, we refer to our rating procedure as "Vendor Quality Conformance." With such a title no misunderstanding is possible. It is merely a measure of how well the quality found conforms with quality standards or AQL's.

In the past, we classified the conformance into three categories—Excellent, Acceptable, and Undesirable. This created some difficulties because this approach utilized the number of shipments and the number of pieces in the sample, i.e., sample size. Some vendors delivering excellent quality could never get into an Excellent category because they were not permitted, due to ordering, to make enough shipments during an evaluation period to accumulate enough credits to fall into an Excellent category. This, of course, is not the vendor's fault, and does cause some embarrassing questions. Such a vendor has a perfect right to ask why. He has shipped commodities with excellent quality, therefore, he should be classified as excellent. By changing the categorical classifications from Excellent, Acceptable, and Undesirable to Acceptable and Unacceptable, this difficulty is eliminated.

If one were to look at quality, in terms of quality, it is either good or bad. The quality meets our standard or it doesn't. By changing our categories into Acceptable and Unacceptable, we feel we are revealing a true quality classification.

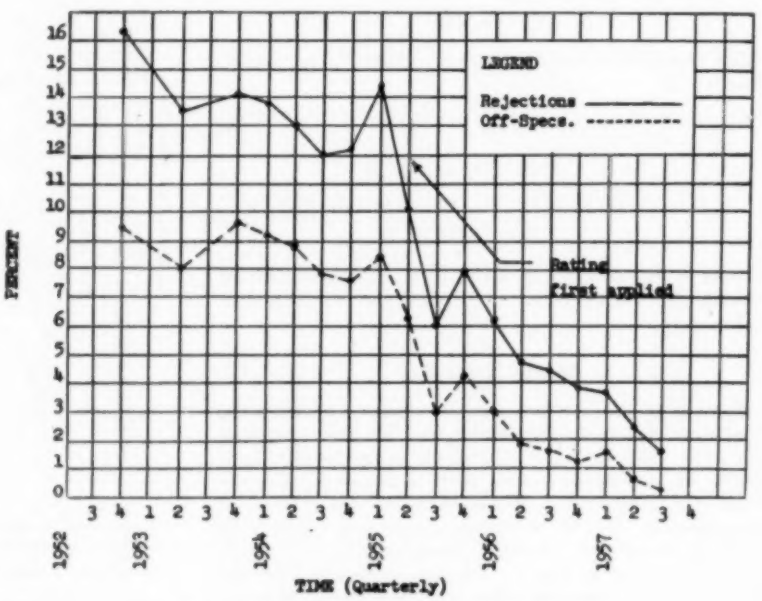

Figure 1—Quality Trend Chart (Purchased Parts)

Method Simplified

Our experience has indicated that many people concerned with quality were of the opinion that a vendor quality conformance procedure could be devised to permit quick calculations. The vendor wanted to be able to compute for himself the conformance we had calculated for him on our electronic computors. This is a natural desire. We believe the procedure we have developed meets the requirements of simplicity, speed, and soundness.

It may be well to review our previous approach in computing ratings. Most of our parts have more than one AQL assigned to them. Since the conformance is a measure of quality deviation from the AQL, it is necessary to compute an index for each individual AQL and then combine these indices into a lot index. The quality conformance is determined from the lot indices during the evaluation period.

The AQL rating of the past was computed by the formula

$$\text{AQL Rating} = \frac{p_1 - p_2}{\sqrt{\frac{p_1(1-p_1)}{n}}}$$

where

p_1 = AQL in decimal form

p_2 = fraction defective per AQL class

n = sample size

The AQL index now is computed by the formula

$$\text{AQL index} = K\sqrt{n}\ (p_1 - p_2)$$

where

K = a constant based on the AQL*

n = sample size

*Derivation of K is in the Appendix.

p_1 = AQL in decimal form

p_2 = fraction defective per AQL class

Since K is constant, and n is also constant, we were able to construct Table I. This is a three dimensional type table which has the dimensions of the horizontal scale in n, the vertical scale in K, and the third in the product of $K\sqrt{n}$. All one need do is select the proper n and AQL scales and where they intersect, the product $K\sqrt{n}$ is found.

Such an arrangement permits speedy computations of the AQL indices. By subtracting the fraction defective (p_2) from the AQL in decimal form (p_1), and multiplying their difference by the $K\sqrt{n}$ factor selected from Table I, a quick computation of the AQL index is accomplished.

The lot index is computed by taking the average of the AQL indices. The lot index for each shipment is calculated in this manner and added into a grand total.

The previous method of classifying quality used the formula

$$\text{Quality Rating} = 70 + 10\frac{(\Sigma LR)}{\sqrt{N}}$$

with: 70 = base point where the total percent defective was equal to the AQL. This value is based upon the grading system of schools.

10 = a conversion factor to convert the lot ratings into the proper units.

ΣLR = sum of lot ratings.

N = number of shipments.

The new approach has simplified this section also. Since the quality conformance should be a method of determining significant deviation of quality from the AQL, and two classifications accomplish this, the base point (70) and the conversion factor (10) are no longer necessary. However, since it is necessary to have a decision point as to where acceptable quality begins and unacceptable quality ends, the critical value −2 has been chosen as this point.

This −2 value can be explained as follows. The AQL index is in the form of a standard normal deviate, so that if we assume this index to be normally distributed, there is about a 2.25 percent chance that a supplier who is shipping AQL quality will have the index for his shipments fall below −2. Hence, every quality conformance that is equal to or greater than −2 in the plus direction is considered as acceptable. Those less than −2 are considered as unacceptable.

Case Example

The following example explains the use of the formula.

During an evaluation period, a hypothetical Vendor, "ABC Corp.", shipped seven (7) shipments, with inspection results as listed in Table II.

Since the AQL index formula requires three multipliers, two of which (K and n) are constant, depending upon the sample size and the AQL used, Table I has been computed to accomplish this task automatically. All one need do is use the number found at the intersection of the column of the sample

TABLE I—Values of $K/\sqrt{n}$

	n	2	3	5	7	10	15	22	25	30	35	45	50	60	75	90	100	150	200	300	500	1000
AQL	K $\sqrt{n}$	1.41	1.73	2.24	2.65	3.16	3.87	4.69	5.0	5.48	5.9	6.7	7.07	7.75	8.66	9.49	10.0	12.3	14.2	17.3	22.4	31.7
0.15	25.8	37	45	58	68	82	100	121	129	141	152	173	183	200	223	245	258	317	366	446	578	818
0.25	20.0	28	35	45	53	63	77	94	100	110	118	134	141	155	173	190	200	246	284	346	448	634
0.40	15.8	22	27	35	42	50	61	74	79	87	91	106	111	122	137	150	158	194	224	273	354	500
0.65	12.5	18	22	28	33	40	48	58	62	68	74	84	88	97	108	119	125	154	178	216	280	391
1.0	10.0	14	17	22	27	32	39	47	50	55	59	67	71	77.5	87	95	100	123	142	173	224	317
1.5	8.2	12	14	18	22	26	32	38	41	45	48	55	58	64	71	78	82	100	116	142	184	260
2.5	6.4	9	11	14	17	20	25	30	32	35	38	43	45	50	55	61	64	79	90	110	143	203
4.0	5.1	7	9	11	14	16	20	24	26	28	31	34	36	40	44	48	51	63	72	88	114	162
6.5	4.1	6	7	9	10	13	16	19	21	22	24	27	29	32	36	39	41	50	58	71	92	130
10.0	3.3	5	6	7	9	10	13	15	17	18	19	22	23	26	29	31	33	41	47	57	74	105

TABLE II—Evaluation of ABC Corporation Shipments

SHIPMENT	QUANTITY RECEIVED	SAMPLE SIZE	AQL	DEFECTS PER AQL CLASS 1.0	1.5	2.5	4.0	AQL INDEX 1.0	1.5	2.5	4.0	LOT INDEX
1	2600	50	1.0, 4.0	0			0	0.710			1.440	1.075
2	76	7	1.0, 2.5	0		0		0.270		0.425		0.348
3	80	15	1.0, 2.5	0		0		0.390		0.625		0.508
4	105	15	1.0, 2.5	5		0		−12.597		0.625		−5.986
5	201	10	1.5, 2.5		3	0			−7.410	0.500		−3.455
6	50	7	2.5			0				0.425		0.425
7	1100	75	2.5			0				1.375		1.375
												−5.710
												Sum of lot indices

Note: *Shipment 4 consisted of 105 pieces from which a random sample of 15 was selected. There were two (2) AQL's used, i.e., 1 percent and 2.5 percent with 5 defectives found on the 1 percent AQL characteristics and none on the 2.5 percent characteristics.*

size, and the line of the AQL. (Example: The number to use when the AQL is 2.5 with a sample size of 15 is "25".)

By multiplying the proper number found in Table I by the deviation, if any, of the quality received from the standard or quality expected (p_1-p_2), we arrive at the AQL Index, shown in Table II.

The actual computations of the AQL index for shipment #4 is as follows.

This shipment was a commodity having two characteristics, one of which was inspected to a 1.0 AQL, the other to a 2.5 AQL. From a sample of 15 pieces, 5 were found defective at the 1.0 AQL and none were found defective at the 2.5 AQL.

From Table I the product of K and $\sqrt{n}$ for the 1.0 AQL is "39", and for the 2.5 AQL it is "25". On the 1.0 AQL, the deviation of the quality received from the standard is (p_1-p_2) or $0.01 - 5/15$ or -0.323. The AQL index calculation is $(39)(-0.323) = -12.597$. Since the deviation on the 2.5 AQL is $(0.025-0)$, we multiply $(0.025)(25)$ and get 0.625. The lot index is the average of the AQL indices.

$$\text{L.I.} = \frac{-12.597 + 0.625}{2} = -5.986$$

The individual lot indices are also shown in Table II.

The Quality Conformance formula is then used

$$\text{Q.C.} = \frac{\text{L.I.}}{\sqrt{N}}$$

$$= \frac{-5.710}{\sqrt{7}} = -2.16$$

Defects Per Unit

The same procedure can be used for complex commodity where a Defects Per Unit Inspection Plan is necessary. In order to use the same procedures, it is necessary to use conversion factors in place of the AQL's. Table III is a listing of these conversion factors. This table is a listing of the converted AQL's in decimal form and is the value to substitute for p_1 of the quality conformance formula. The use of Table IV is similar to Table I and is the computation of $K\sqrt{n}$ for Defects Per Units. (This approach is necessary because the use of the Defects Per Unit AQL's would result in an imaginary number or the square root of a negative number).

TABLE IV—$K\sqrt{n}$ Value for Defects Per Unit Conversion Table

Conv. Factor	n	$K\sqrt{n}$	Conv. Factor	n	$K\sqrt{n}$	Conv. Factor	n	$K\sqrt{n}$	Conv. Factor	n	$K\sqrt{n}$
0.04	25	2.5	0.29	7	0.492	0.96	25	0.51	2.43	7	0.172
0.06	35	2.4	0.29	35	1.1	1.00	2	0.14	2.50	2	0.091
0.06	50	2.88	0.30	10	0.580	1.00	3	0.173	2.67	3	0.107
0.07	15	1.47	0.33	3	0.302	1.00	5	0.224	3.02	50	0.414
0.08	25	1.77	0.40	5	0.357	1.00	7	0.215	3.14	35	0.339
0.08	50	2.51	0.40	50	1.06	1.00	10	0.317	3.20	25	0.284
0.09	35	1.97	0.42	7	0.408	1.00	15	0.388	3.36	50	0.393
0.10	10	1.0	0.43	35	0.9	1.33	15	0.340	3.40	15	0.215
0.12	25	1.44	0.44	25	0.755	1.34	50	0.616	3.60	10	0.170
0.12	50	2.04	0.47	15	0.566	1.37	35	0.51	3.70	7	0.140
0.13	15	1.08	0.50	2	0.202	1.40	25	0.427	3.80	5	0.117
0.14	7	0.712	0.50	10	0.450	1.50	2	0.117	4.00	2	0.072
0.14	35	1.59	0.60	5	0.292	1.50	10	0.26	4.00	3	0.089
0.18	50	1.66	0.60	50	0.92	1.57	7	0.214	4.80	35	0.277
0.20	5	0.505	0.63	35	0.75	1.60	5	0.179	5.00	25	0.230
0.20	10	0.714	0.64	25	0.625	1.67	3	0.135	5.20	15	0.175
0.20	15	0.875	0.67	3	0.213	1.92	50	0.512	5.40	10	0.140
0.20	25	1.13	0.67	15	0.478	1.96	35	0.43	5.60	7	0.115
0.20	35	1.33	0.70	10	0.38	2.04	25	0.354	5.80	5	0.096
0.26	50	1.39	0.72	7	0.313	2.20	15	0.264	6.00	2	0.0595
0.27	15	0.745	0.92	50	0.744	2.30	10	0.211	6.00	3	0.073
0.28	25	0.945	0.95	35	0.61	2.40	5	0.146			

TABLE III—Conversion Factor for Defects Per Unit

SAMPLE SIZE	AQL 0.025	0.040	0.065	0.10	0.15	0.25	0.4	0.65	1.0	1.5	2.5	4.0
2	——	——	——	——	0.50	0.50	0.50	1.00	1.50	2.50	4.00	6.00
3	——	——	——	——	0.33	0.33	0.67	1.00	1.67	2.67	4.00	6.00
5	——	——	——	0.20	0.20	0.40	0.60	1.00	1.60	2.40	3.80	5.80
7	——	——	0.14	0.14	0.29	0.42	0.72	1.00	1.57	2.43	3.70	5.60
10	——	0.10	0.10	0.20	0.30	0.50	0.70	1.00	1.50	2.30	3.60	5.40
15	0.07	0.07	0.13	0.20	0.27	0.47	0.67	1.00	1.33	2.20	3.40	5.20
25	0.04	0.08	0.12	0.20	0.28	0.44	0.64	0.96	1.40	2.04	3.20	5.00
35	0.06	0.09	0.14	0.20	0.29	0.43	0.63	0.95	1.37	1.96	3.14	4.80
50	0.06	0.08	0.12	0.18	0.26	0.40	0.60	0.92	1.34	1.92	3.02	3.36

Directions For Use

The inspection tables based on MIL-STD-105A should still be used to determine the proper sampling plan for any specified AQL. After the sample size and acceptance numbers have been determined from MIL-STD-105A and the sampling inspection is completed, then the following procedure is brought into play.

For the specified AQL and sample size, the number found in Table III (conversion factor) is the p_1 value used in the AQL index formula. The value found by dividing the number of *defects*, not defectives, with the sample size, or number of units inspected, is p_2. The difference found by subtracting p_2 from p_1 or (p_1-p_2) is multiplied by the proper $K\sqrt{n}$ factor found in Table IV. This product is the resultant AQL index. If there is only one AQL, this then is the lot index. If there is more than one AQL, then the lot index is determined by averaging all the AQL's for the particular unit.

Case Example

The following example explains the use of Tables III and IV.

TABLE V

SHIPMENT	QUANTITY RECEIVED	SAMPLE SIZE	AQL	DEFECTS	CONVERSION FACTOR	LOT INDEX
1	16	5	1.00	4	1.60	0.143
2	9	3	0.65	0	1.00	0.173
3	28	7	0.65	5	1.00	0.061
4	6	2	2.50	0	4.00	0.288
5	4	2	1.50	0	2.50	0.228
6	18	5	0.65	10	1.00	−0.224
7	30	7	1.00	0	1.57	0.336
8	9	3	0.25	0	0.33	0.100
9	20	5	1.00	0	1.60	0.286
						1.391 Sum of lot indices

Note: *Shipment 6 consisted of 18 complex units from which a sample of 5 was selected at random. An AQL of 0.65 was used with 10 defects found.*

During a period, a hypothetical vendor shipped 9 shipments which are listed in Table V.

The conversion factor of 1.00 from Table III is used as p_1 in the AQL index formula. This factor is explained in the Appendix. It is also used in determining the proper $K\sqrt{n}$ value from Table IV. By entering Table IV, we find for a factor of 1.00 and a sample size of 5 the $K\sqrt{n}$ factor is 0.224.

Referring to shipment 6, the AQL index is computed by multiplying the $K\sqrt{n}$ factor of 0.224 by the difference between the conversion factor and the ratio of the defects to the sample size.

$$\text{AQL index} = K\sqrt{n}\,(p_1 - p_2).$$

$$= 0.224\left(1.00 - \frac{10}{5}\right)$$

$$= -0.224$$

Since there is only one AQL, the AQL index automatically becomes the lot index. If we had more than one AQL, we would compute the individual indices and combine them into a lot index.

The individual lot indices are also shown in Table V.

The Quality Conformance formula is then used

$$\text{Q.C.} = \frac{\Sigma \text{L.I.}}{\sqrt{N}}$$

$$= \frac{1.391}{\sqrt{9}} = 0.464$$

The vendor quality conformance system is devised so that it is performed periodically, either monthly or quarterly. At the end of a period the quality is given a classification which is kept confidential between the individual vendor and IBM.

A vendor with an acceptable classification is informed that the quality of the commodities he has delivered is within the AQL. It may be that the quality is above or just below the AQL.

An unacceptable classification may be considered as a caution signal. It means that the quality of the shipment is below the standard required by IBM and that it would be advisable to determine the cause and to rectify it.

This procedure and philosophy of measuring quality conformance has shown considerable savings in calculating time. It has increased our card system computation rate from 40 cards per minute to 150 cards per minute because several program steps have been eliminated. We have also cut down the time for hand calculation tremendously. And we have had many favorable comments by our vendors with respect to the new simplified system.

With the increasing complexity of our equipment, component reliability is becoming more important. With a Vendor Quality Conformance system as a tool in establishing good vendors, component reliability is becoming a reality.

Appendix

Derivation of AQL index

$$\text{AQL index} = \frac{p_1 - p_2}{\sqrt{\dfrac{p_1\,(1-p_1)}{n}}}$$

This may be written as

$$\text{AQL index} = \frac{1}{\sqrt{\dfrac{p_1(1-p_1)}{n}}}\,(p_1 - p_2)$$

$$= \frac{1}{\sqrt{p_1(1-p_1)}}\sqrt{n}\,(p_1 - p_2)$$

Since the fraction $1/\sqrt{p_1(1-p_1)}$ has only one variable "p_1", which is the AQL and which is constant for any one AQL, then it can be represented by the constant K, whence

$$\text{AQL index} = K\sqrt{n}\,(p_1 - p_2).$$

For example when AQL = 2.5 = p_1

$$K = \frac{1}{\sqrt{p_1(1-p_1)}}$$

$$= \frac{1}{\sqrt{0.025\ (1-0.025)}}$$

$$= \frac{1}{\sqrt{0.0244}}$$

$$= \frac{1}{0.156}$$

$$= 6.4$$

Derivation of Table III

Reference is made to MIL-STD-105A defects per unit sampling. For an AQL class of 70-109 defects per hundred units, and a lot size of 30, these tables specify a random sample of 7 with an acceptance number of 11 defects. Each point on Table III is the ratio of defects allowed by the sample size needed. For our illustration,

$$11 \div 7 = 1.57$$

Derivation of Table IV

This table has been computed similarly to Table I. The conversion factor is used for p_1 in the formula for K. For instance, K is computed as follows using a conversion factor of 4.00.

$$K = \frac{1}{\sqrt{p_1\ (1-p_1)}}$$

$$= \frac{1}{\sqrt{p_1(1-p_1)}}$$

$$= \frac{1}{0.196}$$

$$= 5.1$$

The $K\sqrt{n}$ value is computed from a sample size of 2 by making the multiplication $5.1\sqrt{2} = 7.24$. We now divide this by 100 and arrive at the value in Table IV as 0.072. The division by 100 was done because defects per unit are in a decimal fraction form multiplied by 100. We eliminate the 100 by dividing.

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Fitzgibbons, Robert G., "The Bendix Radio Vendor Quality Rating System," *Industrial Quality Control*, Vol. XI, No. 8, May 1955, p. 38

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A Guide to the Use of Statistics in the Chemical Industry*

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Introduction

Chemical manufacturing generally implies a series of steps in which both physical and chemical changes are made to the raw material. The beginning ingredient may be a natural product, such as ore, sand, clay, rosin, wood chips, air, water, etc., or it may be the by-product of another chemical operation such as coke manufacture, oil cracking, etc. To control these processes, the engineer must be prepared to consider problems associated with *properties* of the raw materials, intermediates and final products; with large scale *material handling* (liquids, solids, and gases by carload, by barge or direct by pipeline); with *characteristics* of the unit processes or operations themselves; and with the *measurement methods* of the control laboratory. Due to short term obsolescence of many processes in light of new knowledge and changing market demands, he must be ready to utilize the latest techniques for control and to convert the results of new research into profitable production.

In considering where to start with statistical methods,† the engineer must decide between the most logical application—the control (or analytical) laboratory, and the most profitable long term application—research and development. To further complicate the issue, the greatest immediate return may be in improving manufacturing control enabling higher conversions, larger yields, less scrap and waste, fewer recycles for reworking—in general, "tightening up the process."

Applications in Research and Development

As systematic as the scientific method is, it does not tell the experimenter where to probe or when to stop. Neither do statistical techniques specify areas for chemical research, but they can shorten the time necessary to locate areas for profitable investigation. If thought of as decision rules, the philosophy of statistical methods can be rapidly appreciated. Specifically, the methods can aid the experimenter in laying out or designing tests and experimental programs so that (1) the inferences made can be as broad as possible rather than restricted, (2) the experimental results can be compared with outcomes of other test programs, (3) the results can be measured against estimates of experimental "error" or variability associated with the test rather than some ideal or guess, and (4) the results will suggest the next areas to be investigated.

Large advances are to be expected in research and development using statistics, mainly because invention is a virtually unknown process itself. Anything that can be done to shorten the total period increases research productivity. Specifically, the "preparation" stage can be shortened if sharp, clean-cut experiments are made during early data collection. Good statistical usage aids in suggesting hypotheses. Careful test layout produces experimental results that may be combined with other tests, hence providing a common basis for extension to new ideas. Once through the "incubation" and "illumination" stages of reflective thinking, statistical methods again play a large part in describing ways to verify suggested hypotheses and thus lead to profitable revision. Additional insight into types of problems which can be answered is given in Table II.

TABLE I—Classification of Statistical Usage By Organizational Function

Statistical Tool	Research Development, Process Improvement	Process Control	Control Lab.	Process and Equipment Design
descriptive statistics	x	x	x	x
frequency distributions	x	x	x	x
control charts	x	x	x	
significance tests	x		x	x
analysis of variance	x		x	
experimental design	x	x	x	
multiple regression	x			x
simple regression	x		x	x
curve fitting	x			
tests of normality	x			
acceptance sampling			x	
analysis of counted data	x		x	
"short cut" methods		x	x	
process capability		x		
scatter diagrams	x		x	
confidence limits	x		x	x
tolerance limits	x	x	x	x
Hotelling's generalized T	x	x		
covariance	x			
discriminant functions	x			

*Presented at the 12th Annual ASQC Convention, Boston, Mass., May 1958.

†Table I summarizes typical uses of statistical methods in various chemical fields.

Applications in the Control Laboratory

To the experienced statistician the control laboratory has obvious needs for statistical assistance. Its processes are repetitive, involve measurements, calibrations, comparisons with standards or expected values, and ultimately, decisions for action. Very frequently, the process being observed is sampled rather than continuously monitored. If analysis is expensive or time consuming several samples may be composited and a portion of the total analyzed. Application of statistical methods to each of these problems will assist the analytical chemist in reaching adequately accurate, precise and reliable decisions at minimum cost. Table III suggests typical problems and general methods of attack.

"Start in the control laboratory," is often advocated to the beginning statistical investigator. Statistical applications in other areas frequently lead to an examination of the analytical measuring method before significant progress can be made. This seems true in either experimental design or process engineering problems under study. The policy rests on the axiom, "no measurement method is reliable unless it demonstrates statistical control." Hence, the reaction, "if you will eventually have to study the control lab, why not start there?"

Applications in Process Control

The use of statistics in process engineering has appeal to chemical engineers because they find in it ways of making distinctions between natural process fluctuations and reaction variations accountable for material losses, increased processing time, lowered product quality, or lower yields. Experience has shown many operating engineers that unnecessary process "adjustments" are made. Little progress is made in reducing to theory the dominating "rules of thumb" unless the inherent process behavior is well understood. Statistical techniques, in the form of control charts, designed plant tests, single or multiple regression and others mentioned in Tables I and IV, assist the control engineer in his continual effort to restrict the process no more than necessary to obtain the due economic return.

The process engineer frequently needs special tools to deal with related variables. Control by the use of separate control charts on each of several correlated variables can be misleading; corrective action being unnecessarily taken at times, and on other occasions no action initiated when drastic steps may have been necessary. A control chart based on the generalized T can properly handle such problems.*

While investigating process difficulties the chemical engineer may have to decide which variables to measure, record and interpret. Variables thought to be "fringe" factors may be tabulated for the record rather than varied, with the usual outcome that on analysis the engineer is never sure whether the major factors selected or the concomitant factors are responsible for the observed changes. Fortunately, covariance analysis* equips the engineer to test the influence of these questionable variables. Their effect can be separated from that of the treatments under study to improve the experiment's sensitivity. If significant, the relation established between the covariables and the main factors can be used for additional

*See Jackson, J. E., "Quality Control Methods For Two Related Variables," *Industrial Quality Control*, Vol. XII, No. 7, Jan. 1956 and Hicks, C. R., "Some Applications of Hotelling's T," *Industrial Quality Control*, Vol. XI, No. 9, June 1955.

*See *Biometrics*, Vol. 13, No. 3, Sept. 1957, p. 261—405 for seven recent papers on covariance.

TABLE II—General Problems Suited to Statistical Treatment in Resarch and Development

Problem	Analysis	Statistical Approach
1. How should experiments be planned to maximize information received for a given cost or effort?	1. Define problem. Identify major and minor variables. Select ranges within which to test. Estimate experimental error. Set goal for improvement acceptable. Set failure risks and consequences. Consider interpretations of possible outcomes of experiment.	1. From risks set, degree of improvement wanted, estimated experimental error, determine sample size (n). Select a design to maximize power for a given sample size. Balance and/or randomize to provide internal estimate of experimental error. Compare design with reality; modify. Sacrifice interactions when necessary for broader design.
2. Which experimental designs are best suited to find *optimum conditions*?	2. Depends on "response system". If any knowledge of this is available, select an experimental design best suited to it.	2. One-at-a-time method. Box-Wilson steepest ascent using factorials, fractional replicates, multi-factor designs.
3. What methods are best suited for *comparing different levels* of process operation?	3. Is previous estimate of process variability at hand? How large a difference is important?	3. With an estimate, use control charts. Without, use analysis of variance.
4. Plant variables cannot all be changed at once. What can be done?	4. Plan experiments so smallest expected changes are tested first to verify knowledge of process. Then make other changes gradually. Reset variables as best possible to initial conditions.	4. Use multiple regression to study influence of factors. Use control charts during tests to spot unusual behavior. Avoid confounding variables with time wherever possible. Use "Evolutionary Operations" method during regular production.
5. Several apparently extraneous factors may have influence, but this is uncertain. How do you measure and correct for this?	5. Take measurements on them simultaneously with variables under study.	5. Use covariance methods to determine if they are significant factors. Covariance essentially adjusts data to average of concomitant factors. If found significant include in next test.

TABLE III—Control Laboratory Uses of Statistical Methods

Problem	Analysis	Statistical Approach
1. Describe a procedure to verify that routine lab methods are reliable.	1. Reliability requires the state of statistical control and implies that adequate accuracy and precision are present.	1. Use control charts to test for control. Establish accuracy in comparisons against a standard. Verify precision from standard deviation.
2. How can lab processes be monitored to maintain control?	2. Comparison against standard performance is implied. Necessary to establish process capability, then compare performance with this.	2. Submit "blind" samples as checks. Plot on control chart as difference from 1st analysis. Analysis of variance to establish inherrent variability of method.
3. Should a submitted sample be analyzed in replicate? as a composite? or in duplicate?	3. What confidence limits are wanted on the mean result? Is a sample of 1 sufficient?	3. Use analysis of variance to identify size of residual errors, sampling, and processing. Note that duplicates are for gross blunder control only.
4. How can product acceptance information be used in process control?	4. Establish correlation of product characteristic and processing variable creating or controlling this. Is product in control?	4. Simple or multiple regression to establish correlation. Control charts. Acceptance plan may be lot by lot variables sampling, or continuous AOQL.
5. Which analytical method is more precise? more accurate?	5. Compare standard deviations for precision; mean with a standard for accuracy.	5. Significance tests; variance omnibus test or analysis of variance.

TABLE IV—Process Control Uses of Statistical Methods

Statement of Problem	Analysis	Statistical Approach
1. How should a process be controlled?	1. What are the process variables? Which are strongest? Which are measurable and controllable? What points in process are most sensitive, most representative?	1. Make "process capability" study of strongest variables at points in process to verify knowledge and establish state of control. (use individuals control charts, moving range charts)
2. Will a process meet specifications?	2. Are the specs. well defined? Are test methods available for all parts of specs.?	2. Is process in statistical control? at right level? with right dispersion? (control charts: normal area)
3. How often should the process be sampled?	3. What are the consequences if it changes from standard values? What does it cost to sample and test? How often is it likely to go out of control?	3. Economic balance of value vs. cost. Power of control chart vs. sample size. Auxiliary use of "runs", t-σ limits, extreme value theory.
4. How should a bulk sample be taken and used?	4. What is known of its history? Is material stratified? Is average or dispersion of interest? How variable is the product? Can the process be sampled prior to bulking?	4. Analysis of variance to establish sampling variability. Compare various ways of taking sample to establish size of stratification effect.

test planning, data analysis and interpretation. In many cases, experiments with negative outcomes have had their conclusions reversed upon proper statistical analysis of this type.

The development engineer attached to an operating division must conduct his plant scale experiments so that any losses incurred are minimized. This usually means that the variables under test are restricted in range, and also that the combinations of variables chosen have been carefully screened to avoid large reductions in yield, quality loss, etc.* Finally, the test order is not likely to be randomized mainly due to the cost of bringing the process to equilibrium under new conditions. These factors force the chemical engineer to carefully examine any experimental plan well in advance of its inception to be certain that the interpretations or inferences likely to be made will be justified.†

A Process Development Example

As part of a regular procedure for evaluating new process equipment, an automatic liquid-liquid separator was installed on a batch nitration kettle. In operation, the entire charge of acid and nitrated organic was dropped into the separator at the end of the nitration cycle. The separated acid overflowed to the recovery plant. When it stopped, the organic "oil" was drawn off to a scale tank and weighed. The automatic separator was expected to be quicker and more uniform than manual operation. To test this expectation, operating records for 5 days previous to startup were examined to establish a baseline for comparison. Figure 1 shows the daily average charge weight and daily weight standard deviation before and after installing the unit. The "before" control chart limits were originally extended beyond the 5 days, but have been redrawn in Fig. 1 to emphasize the changes in average and uniformity in the "after separator" period.

The control charts focussed attention on a number of important processing conditions:

(1) a small but significant increase in yield of oil occurred (30 ± 12.8 lb. per charge). (Because of production volume this 1 percent increase would net an extra 10 ton per month product at this stage, worth about $29,000 per yr.)

(2) the batch-to-batch variation decreased to *one-sixth* its former size with indications it might reduce even further.

(3) the combination of increased yield and decreased variation meant that the next nitration kettle could operate at close to 100 percent capacity. Until the separator and the rest of the plant became stabilized at a new level, the production supervisor limited the amount of oil to be drawn off from the separator. This showed up as two "out-of-control" points on the average chart immediately after startup. As soon as it was obvious, from observing the oil level in the separator, that batch-to-batch variation had been markedly reduced

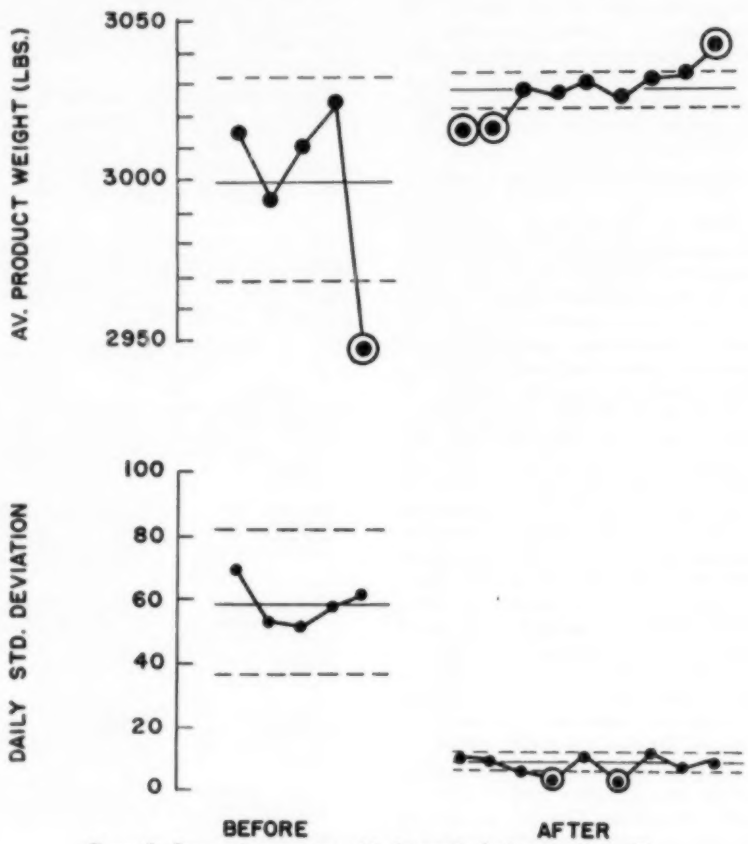

Figure 1—Process Improvement with Automatic Equipment (N = 32)

*See Box, G. E. P., "Evolutionary Operations," *Applied Statistics*, Vol. VI, No. 2, (1957) for methods to use plant operation to generate better processes.

†Box, G. E. P., "Multi-factor Designs of First Order," *Biometrika*, Vol. 39, No. 49, (1957) for methods to use plant operation to randomization for eliminating trends of extraneous effects.

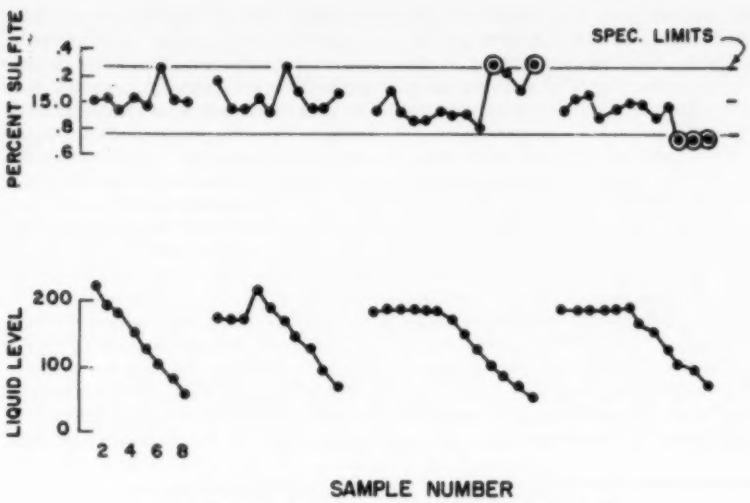

Figure 2—Variation in Solution Strength with Liquid Level

the separator was allowed to seek its own level. This procedure minimized the chance of the increased oil yield overflowing the kettle in the following stage.

In this case, the control charts dramatically showed the process improvement. The new control limits served as guides until all operating personnel had become familiar with the equipment.

A Control Laboratory Example

During the starting phase of a new plant, the production department complained that it was being held up awaiting laboratory analyses on end-point samples. The analytical results verified when a given batch met specifications and could be released to the next production area. Discussion with the chief chemist of the control laboratory highlighted several possible causes:

(1) The production department was submitting 6-10 samples per tank per shift for analysis. (This turned out to be an attempt on their part to bolster their confidence in laboratory results. The production department had cited several cases where duplicate sample results were widely dispersed and virtually unbelievable.)

(2) The actual analytical time was quite short (about 10 minutes). However, standardization of the "standard" solution frequently took 4-6 hours (considered highly excessive).

(3) The standards chemist believed that results of his standardization tests had to agree within ± 0.01 percent. He reported running as many as 25 analyses on some standard samples. When asked how he used the results he casually admitted ignoring all but the closest four determinations!

At this point, the analytical results for the most important solution constituent were plotted. Also, the production records of tank volume corresponding to times when the samples were taken were examined. From these, liquid level was plotted. Figure 2 shows these results. Checking further, in both cases when points went out of control it was found that the standardizing solution strength had changed.

Equipped with this information it was possible to sell the production department on submitting the minimum number of samples to prove in a batch, and none thereafter; and to redirect the standards chemist's zeal toward finding a more stable standard solution. To help the standards chemist better understand by how much the "low" and "high" results of his standardization could vary a table was compiled (see Table V). The improvement in precision of the average was also shown.

Table V was computed on the assumption that the analytical method variation should be about one-tenth the specification tolerance range, i.e., 0.1 (15.25 − 14.75) or 0.05 percent. Equating this to 6σ made $\sigma = 0.00833$. $\bar{R}$ was calculated from $\bar{R} = d_2\sigma$, UCL_R from $\sigma\ (d_2 + 2d_3)$ and $\pm L = 2\sigma/\sqrt{n}$.* All of the values assumed that the testing technique was kept in control. A check procedure using production samples was established to verify routine analytical precision and accuracy. Routinely, a production sample that had been analyzed on one shift was held over for analysis on a subsequent shift. The difference was plotted on a difference control chart† posted in the lab.

During the development of the new test method the standards chemist was given aid in the form of experimental design. Tests were planned to establish the precision and reliability of each technique as it was evaluated until an acceptable one was found. When an acceptable procedure was found, test limits were calculated by the method of Grubbs and Coon.‡

While the details discussed above appear trivial in terms of statistical sophistication, any attempt at learning such things as the sampling variation of end-point samples, bias in solution strength with tank depth, analyst variation, equipment calibration bias, test method precision, etc. would tend to obscure the real issue. This was one case where a true statement of the problem statistically was not forthcoming until the immediate demands of the problem had been met. Statistics played its part in *recognizing* the effect of variation and *assessing* its relative importance in each of the problem areas.

(Concluded on page 18)

*"ASTM Manual on Quality Control of Materials," *Spec. Tech. Public. 15-C*, January 1951, p. 115.

†An example is given in Bingham, R. S., "Practical Chemical Process Control," *Industrial Quality Control*, Vol. XIII, No. 11, May 1957.

‡Grubbs, F. E. and Coon, H. J., "On Setting Test Limits Relative to Specification Limits," *Industrial Quality Control*, Vol. X, No. 5, Mar. 1954, p. 15-20.

TABLE V—Average and Range Confidence Limits for Various Number of Analyses

Number of Anlyses per Standardization (n)	Dispersion of Results		Precision of Average
	Average Range (R)	Upper Range Limit (UCL_R)*	Confidence Limits For the Average of n Analyses (± L)*
2	0.009	0.024	0.0118
4	0.017	0.032	0.0083
6	0.021	0.035	0.0068
8	0.024	0.037	0.0059
10	0.026	0.039	0.0053
15	0.029	0.042	0.0043
20	0.031	0.043	0.0037
25	0.033	0.045	0.0033

*approximate 95% limits.

The Power of Statistical Methods

In describing statistical methods as engineering tools it is most appropriate to emphasize two aspects of the definition—as a means to an end and as a working implement. Referring to the first, the engineer must not become overawed with his new gadget, but rather see that it is used as planned. As a tool user, the engineer must show due respect, keep it sharp, not expect more than its design capabilities, and finally, realize that in some situations it will neither work nor improve the project and a revision or new design may be required. Special purpose tools have their own restrictions and accept only pieces meeting certain design specifications. Hence, if they are to be used, early stage planning must anticipate their special requirements otherwise their advantages may be lost.

From this we conclude that engineers may sharpen their judgment by appropriately applying statistical techniques whenever needed. Frequently, a chemical problem will seem to have no statistical counterpart. More careful reflection and review of theory will usually provide a direction for attack if only as a first approximation. Careful restatement of the problem will often disclose new approaches and suggest hypotheses for examination.

Early uses of statistical methods may disappoint engineers, usually because confidence limits are wider than thought necessary, mainly due to underestimation of experimental errors. However, repeated use, especially in ferreting causes of wide variability, generally leads to reduction in the experimental error and an improvement in decision making. It is important to note that the statistical techniques were not responsible for either the initial or final conditions; rather, they measured and pointed out the size of the variability and/or its form, leaving the correction to the scientist. This seemingly small contribution is increasing in scope daily in the chemical industry.

Some Theoretical and Practical Aspects of

Tolerances for Mating Parts

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Introduction

The aim of this article is to help bridge the gap between two opposing viewpoints.

On the one hand is the old-line, conservative designer who draws up specifications so that if the parts are all within their respective specifications the assembly will still work, even though the parts are at their worst extremes. On the other hand are the statistical enthusiasts who want to use laws like $\sqrt{(\text{toler.}_1)^2 + (\text{toler.}_2)^2}$ on all assemblies. The former having been around much longer are "in the saddle," and I must admit to a heartfelt "thank goodness" in a great many cases.

We want to consider here how we can help designers make use of statistical laws to make satisfactory assemblies safely and more cheaply. This can only be achieved by a subtle blending of the theoretical and practical.

Importance of Assumptions

Much has already been written on this subject from various standpoints. (For example, see References 1, 2, and 3.) To make use of the statistical laws, the assumptions must be met.

One of these is that the parts are to be assembled in random order. This can be accomplished by (1) having the processes in control, (2) mixing the product after manufacturing, or (3) assembling parts by random choice from a sizable production lot. The distribution in question then is that of the over-all production including out-of-controlness in (2) or (3).

The second assumption is that we know something about the distribution within the various tolerance ranges. We must treat a great deal differently such cases as (1) a normal curve just nicely meeting specifications without any sorting (say, 0.5 percent or so outside), (2) a normal curve much narrower than the specified tolerance but located quite near either the upper or lower specification, (3) a skewed distribution butting right up against the upper or lower specification (such as results from eccentricities close to zero or from 100 percent sorting, rework, sorting, etc. as in outside and inside diameters), and (4) a distribution which substantially fills the tolerance range through very heavy 100 percent sorting on both ends.

The third general assumption is that specifications are not "interpreted". By this we mean the tendency of some inspectors and inspection foremen to take it upon themselves to expand the tolerance to let more product through, which they judge will not do any harm. It must be admitted here that this tendency has been encouraged by (1) design engineers specifying tighter tolerances than they really need, and (2) undue pressure from production to let it get through.

If the foregoing assumptions cannot be met, then there is little left but to adopt the old attitude of conservatism, with its attendant unrealistic treatment of specifications that are deemed too tight by production and "interpreted" by inspection. But if a company will do something about each of these three assumptions, then the door can be opened to some large, even enormous, savings.

Fortunately statistical quality control can help significantly on all three assumptions. In the first place, the control chart is naturally adapted to getting processes into control, and at the least variability of which the

process is capable. Secondly, frequency charts of part measurements tell us what distributions we have within specifications. Moreover, gaining control of processes and learning to center them better gives us better distributions, perhaps even to the ideal of a perfectly centered normal distribution not requiring any sorting. Thirdly, when maximum performance is being obtained from the machines and information on process capabilities is regularly sent to design engineers, they can usually considerably expand the tolerances if they can be assured that these will be met by a well-centered process with few parts at either extreme. At least this is what they can do if they are up to date in their knowledge. When such sensible and practical specifications are used, then the problem of "interpreting" should and must disappear.

We cannot get something for nothing in this, that is, we cannot gain the potential fruits of formulas such as $\sqrt{(\text{toler.}_1)^2 + (\text{toler.}_2)^2}$, without taking the effort to meet the assumptions. But if the assembly is of any real economic importance, then we stand to gain enormously by team-work and sound statistical control and theory. The more knowledge and control, the more advantage we can gain from this approach.

Some Statistics of Sums and Differences

Most statistical quality control people are familiar with the general law for

$$Y = X_1 \pm X_2 \pm \ldots \pm X_k \tag{1}$$

where any desired choice of signs may be used. For example, we might have, with $k = 2$, $Y = X_1 - X_2$, or with $k = 3$, $Y = X_1 + X_2 + X_3$.

Then we have

$$\overline{Y'} = \overline{X'}_1 \pm \overline{X'}_2 \pm \ldots \pm \overline{X'}_k \tag{2}$$

This formula, interestingly enough, does not require our first assumption of independence. Next we have

$$\sigma'^2_Y = \sigma'^2_{X_1} + \ldots + \sigma'^2_{X_k} \tag{3}$$

where we must assume independence (or random assembly). If the parts are not independent, then we may have anything between the two extremes

$$\sigma'_Y = \sigma'_{X_1} + \ldots + \sigma'_{X_k} \tag{4}$$

$$\sigma'_Y = 0 \tag{5}$$

The former, (4), is much like what the conservative design engineer uses when he specifies the simple sum of tolerances.

This paragraph deals with two measures of curve-shape α_3 and α_4. They are, respectively, the standardized third and fourth moments about the mean. α_3 measures lack of symmetry, while α_4 measures how relatively rapidly the distribution approaches zero frequency as we go away from the mode. For α_3 we find the third moment around the mean, just as the variance is the second moment around the mean. Having gotten such a third moment, then we divide by σ'^3_X to standardize. Thus

$$\alpha_3 = \frac{E\,[(X - X')^3]}{\sigma'^3_X} \tag{6}$$

$$\alpha_4 = \frac{E\,[(X - X')^4]}{\sigma'^4_X} \tag{7}$$

where E stands for theoretrical expected or average value.

Now for independent X's all from the same population or populations with the same 1st to 4th moments we have, for Y defined as in (1):

$$\alpha_{3:Y} = \frac{\alpha_{3:X}}{\sqrt{k}} \tag{8}$$

$$\alpha_{4:Y} = 3 + \frac{\alpha_{4:X} - 3}{k} \tag{9}$$

It is easily seen that as k increases, the respective moments of Y tend toward 0 and 3. These last are of course the values for the normal curve. If the X's are independent, but not from the same population, then we have the more complicated:

$$\alpha_{3:Y} = \frac{E[(X_1 - \overline{X'}_1)^3] \pm \ldots \pm E[(X_k - \overline{X'}_k)^3]}{[\sigma'^2_{X_1} + \ldots + [\sigma'^2_{X_k}]^{3/2}} \tag{10}$$

$$\alpha_{4:Y} = E[(X_1 - \overline{X'}_1)^4] + \ldots + E[(X_k - \overline{X'}_k)^4] + 6 \sum_{i<j} \sigma'^2_{X_i}\, \sigma'^2_{X_j} / [\sigma'^2_{X_1} + \ldots + \sigma'^2_{X_k}]^2 \tag{11}$$

Now it is widely known that if, for any one distribution having a mean and standard deviation, we take repeated independent observations from this population and add them, we get a variable whose distribution approaches normality as k increases. This is called the Central Limit Theorem. If, however, the X's do not all come from the same population, then a comparatively mild restriction involving the third moment guarantees the approach to normality.[4]

The facts in this section are available in most mathematical statistics texts.

Distribution of Sums and Differences

To many the information given in the preceding paragraph seems to settle the problem. But this is only surely true for "large" numbers of components. How good is it for small numbers? Two experiments by Shewhart[5] show how rapid the approach is with a rectangular and a right triangular population. For just four X's from such populations quite good normality exists. These are, of course, not very "bad" populations. Much worse ones can be found, such as those in life test data.

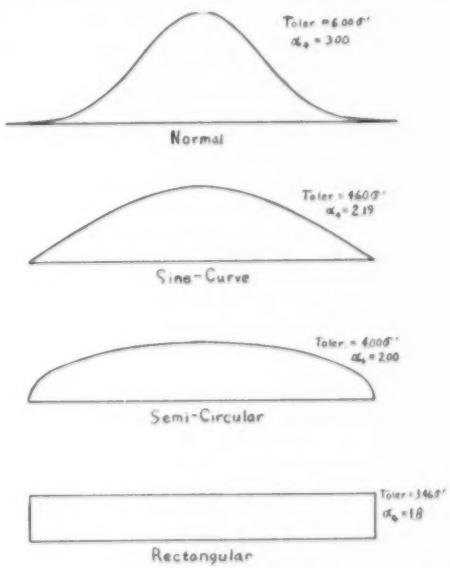


Figure 1—Four Different Populations Drawn With Same Spread and Area (normal with 0.3 percent outside limits)

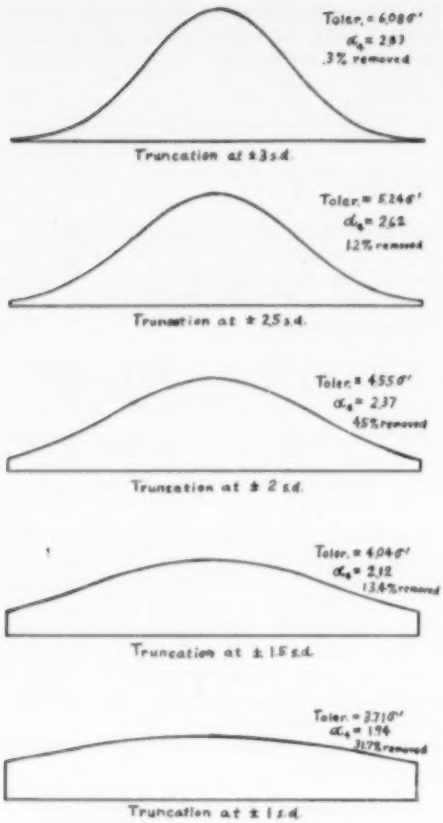


Figure 2—Truncated Normal Populations

Let us consider first the populations given in Fig. 1. At the top is a normal curve with $6\sigma'$ equal to 5 units in the original drawing, hence having 0.27 percent outside of $\pm$ 2.5. The bottom curve shows the rectangular distribution, with the same area, $3\frac{1}{3}$ square units. This is the extreme of heavy 100 percent sorting to chop off the ends. Next to this is the semi-circular curve (a semi-circle in the proper scaling, an ellipse in this), which has been proposed by Gilson[3] as a conservative curve between the normal and rectangular. The fourth curve in Fig. 1 is a "sine curve" distribution dreamed up by the present author as another compromise between the extremes. Since these curves are all symmetrical they all have α_3 zero. The values of α_4 are given for each. The tolerances in terms of standard deviations are given too and they also show a regular progression.

Figure 2 shows the results of truncating a normal population. These were all drawn with the same area and range of 5 units but are to be thought of as truncated at $\pm$ 2.5 units at $\pm$ 3.0, 2.5, 2.0, 1.5 and 1.0 σ' respectively. The respective tolerances in terms of (σ')'s for the distributions as shown, and the α_4's are interesting to compare with those in Fig. 1.

Now what distributions do we get when adding X's from such populations as those in Figures 1 or 2? The case of adding or subtracting two component X's from the same population is given in Fig. 3. The two drawings from a normal curve reproduce another normal curve, as is widely known. Also rather widely known is the A-shaped "roof" distribution from the two rectangulars. (The distribution of totals from the two dice running from $\frac{1}{36}$ for a total of 2 through $\frac{6}{36}$ for 7 to $\frac{1}{36}$ for 12 is a discrete example of this.) The semi-circular distribution, being a lot like the rectangular, reproduces a rounded version of the A-roof, but is already rather normal. The sine distribution yields a quite normal distribution, although we have used but two components.

For unequally distributed rectangular components we can compare those in Fig. 4. With two components there is a horizontal part to the roof, which is short if the components are nearly equal, and long otherwise. For three equally variable components the curve appears quite normal to the eye, but for the given unequally variable components there is a straight section on each side of the curve.

Conclusions on Curve-Shape

When dealing with more or less equally variable distributions of not bad skewness or long tails, we can expect good normality for three or more components, and fair normality on two in at least some cases. Probably in practical cases we are able to assume normality if in using (8) and (9), or (10) and (11), we find that $|\alpha_{3\cdot Y}|$ is not larger than 0.3 and α_4 lies between 2.6 and 3.4. To estimate the values of α_3 and α_4 needed for substitution, we can use those calculated for data at hand, but should have a very minimum of 100 in such samples; 300 would be much more desirable. Also it is not worth calculating these results until we are reasonably sure of this distribution continuing to appear, through the process being stabilized.

How Can the Statistical Principles Be Used in Practice?

As we have seen, information must be gathered on all combining dimensions of the component parts of an assembly. If possible, they should be brought into some semblance of a state of control and, at the very least, dimensions should be aimed at the middle of the specifications. Thus we should avoid running to the high side on outside diameters and to the low side on inside diameters. If the natural process capability is less than the tolerance, it is still a good idea to run to the tolerance middle until the over-all picture is clear. Of course if tool wear is strongly present, we may wish to use the full tolerance. Then random assembly from the product should give a rather flat-topped distribution, perhaps like the sine-curve.

When we have reasonably stable distributions of part dimensions we can use Figures 1 and 2 to estimate α_4 for each one, and also σ' by the proportion of range. If

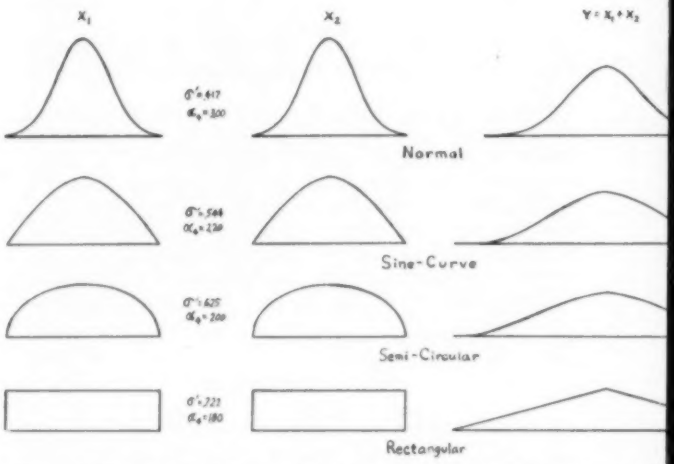
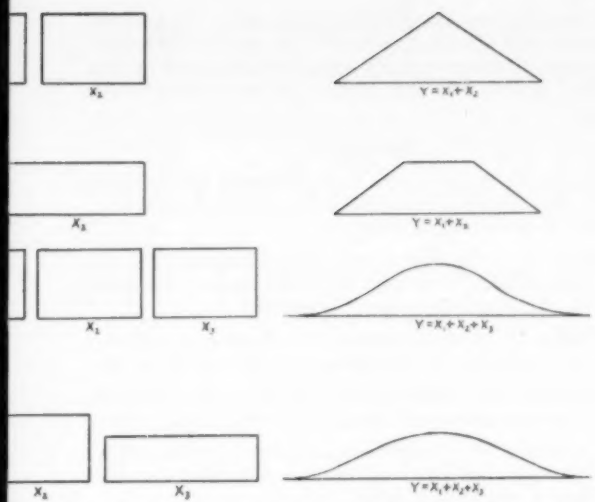


Figure 3—Distribution of Sum of Two Equally Distributed Components for Fo Populations



Distributions Resulting from Adding 2 or 3 Equally or Unequally Rectangular Populations

skewness is not marked, it may be neglected. If it is substantial, then it should be taken into account. We use (9) or (11) to get α_4 for the combination, and if necessary (8) or (10) for α_3. We also find the mean and standard deviation by (2) and (3). This gives us a great deal of information on the distribution of the characteristic in question. If α_3 is between, say, -0.3 and $+0.3$, and α_4 between 2.6 and 3.4, we can safely treat it as a normal curve, and expect practically all Y's to lie inside $\bar{Y} \pm 3\sigma_Y$. Only when α_3 is outside, and/or α_4 above 3.4, can we expect any trouble from a sizeable percentage outside this range. The key is two-fold: (1) to use the actual $\bar{X}$ and σ for the distributions which may, for example, have been truncated by 100 percent sorting, and (2) to estimate α_3 and α_4 for the distributions.

By using this approach we can often enlarge the specifications on those dimensions which are most difficult to hold. In this way it is often possible to: (1) eliminate 100 percent sorting, thereby saving inspection and parts, (2) use a cheaper process, or (3) avoid the necessity of an extra operation. In an example of the last, the author worked on an assembly in which there were 10 dimensions combining. All ten had to be at the very extreme in the respective wrong directions for the parts to just fail to assemble. When this situation was analyzed and presented to the government agency, a relaxation of one dimensional specification was granted, thereby saving an 8¢ operation on each of an order of 4,000,000 parts.

Arthur Bender of Delco-Remy Division of General Motors has given me an example of a 12 volt motor assembly with some 38 dimensions, all adding and subtracting along the shaft. Just as an example, let us suppose that these 38 all had the same tolerance and that the distribution within the specifications were no better than rectangular. Then, if each such tolerance is T, the standard deviation of each rectangular distribution is $\sigma'_X = T/3.46 = T(0.289)$. Now using (3) with all σ's having this value, we find that

$$\sigma'_Y = \sqrt{38}\sigma'_X = T(0.289)\ \sqrt{38} = 1.78T$$

Hence the tolerance which the 38 rectangular distributions can meet is

$$6\sigma'_Y = 10.7T.$$

On the other hand if the frequently used and very conservative straight addition of tolerances were used, then we would have specified a tolerance of 38T, that is, 3.5 times as great as is the tolerance actually being met with the parts meeting specifications no better than rectangularly in each case.

Let us take this problem and get a reverse solution. Suppose that the design engineer decides that the dimension, Y, can really have a tolerance of 38T, and he wishes to give each part-dimension the same break, that is the same tolerance.

Calling

$$6\sigma'_Y = 38T$$

we have

$$\sigma'_Y = 6.33T.$$

Then for Y, the sum-difference combination of 38 measurements, each having standard deviation σ'_X we have

$$\sigma'_Y = \sqrt{38}\ \sigma'_X,$$

and so

$$\sqrt{38}\ \sigma'_X = 6.33T,$$

from which

$$\sigma'_X = \frac{6.33T}{\sqrt{38}} = 1.03T.$$

Thus, instead of specifications being $\pm$ T/2, they can now be $\pm\ 3\sigma'_X = \pm\ 3.09T$, *provided* each such specification will be met by a centered normal curve. The aim, in fact, of any relaxing of tolerances is to permit their being met by a normal curve, so as to eliminate sorting. If at the beginning of this analysis of Bender's problem, the rectangular distributions were the result of sorting a much wider normal curve, such as, the bottom of Fig. 2, and the width of such nearly rectangular curves was T, then to get the whole untruncated normal curve in, we would have to multiply by 3, that is, give a tolerance of 3T. In this 38-dimension problem we have just seen that it would be possible to go to a tolerance of 6.18T, leaving much room for imperfect centering. To make use of such great relaxation of tolerances, however, we would have to be sure that the centering is reasonably good

The foregoing is a quite bizarre case with such a large number of combining dimensions. Let us next take a simpler case in which a designer wants the sum of three parts to meet a tolerance of 0.003 inches. Then he may give a tolerance of 0.001 inches to each part. Suppose that the distribution of each part in its specification is like the middle of Fig. 2. Since, in this distribution, the range is $4.55\sigma'_X$, $\sigma'_X = 0.001$ inches/4.55 = 0.000220 inches. Hence, for the sum of all three, say Y, we have

$$\sigma'_Y = \sigma'_X\ \sqrt{3} = 0.00038 \text{ inches}$$

For $\alpha_{4:Y}$ we have

$$\alpha_{4:Y} = 3 + \frac{\alpha_{4:X} - 3}{3}$$

$$= 3 + \frac{2.37 - 3}{3}$$

$$= 2.79$$

and we can treat this as a normal curve with standard deviation 0.00038 inches. Thus we are actually meeting $\pm$ 3 (0.00038 inches) = $\pm$ 0.0011 inches. So we are meeting the tolerance of 0.003 inches perfectly, with some room to spare, but at a cost of sorting time. Can we do anything about it? Now the middle distribution of Fig. 2 was a 2-σ sorting, that is, the outer tail on each side

from $2\sigma'_X$ onward was removed. Thus for the true process σ'_X before sorting we divide the 0.0005 inches by 2 to get $\sigma'_X = 0.00025$ inches. Now adding three such components we have

$$\sigma'_Y = \sqrt{3}\ \sigma'_X = \sqrt{3}\ (0.00025) \text{ inches} = 0.00043 \text{ inches}$$

$$3\sigma'_Y = 3(0.00043 \text{ inches}) = 0.0013 \text{ inches}$$

and we still can meet ± 0.0015 inches without any sorting, provided we keep the processes in control and centered to the specifications.

The actual practical problems can be solved by using known process capabilities, trying to use distributions just as they are (without sorting), substituting reasonable hypothetical tolerances for the unknown ones and combining by (3). If the desired combined tolerance is not met, then something will have to be removed from one or more component tolerances. If at all possible it is wise to use large enough specifications to permit some variation of process setting. The most economical setting of the system of specifications involves a lot of give-and-take compromise. The big thing is to use in (2) and (3) the mean and standard deviation for each reproducible frequency distribution to be used (including any needed sorting) and to take due account of the various curve shapes.

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Effect of Temperature Conditions and Coefficients of Thermal Expansion on Accurate Gaging

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Problem

In the last few years more and more production and inspection problems have occurred because inspection techniques do not take temperature effects into consideration or because these effects are misinterpreted and erroneously minimized.

New machine tools, design techniques and materials permit, and often require, the machining of dimensions with very small tolerances.

Under present machining conditions these tolerances often become small enough or the dimension itself is large enough so that *serious gaging errors occur because of temperature differences and differences of coefficients of thermal expansion between the pieces being inspected and the gage masters.* (See Appendix I for detailed explanation.)

This article will be limited to the problems encountered using indicator gages with separate gage masters.

The occurrence of anisotropic (non-uniform) changes of materials at normal gaging temperatures is so rare that it will be ignored.

Solutions

Most methods of accurately determining piece size at 68°F. fall into one of two categories.

A. No Gage Reading Compensation Required

Method 1—No gaging error exists when piece and gage master are at 68°F.

Method 2—No significant gage error exists when piece and gage master are at same temperature and have the same coefficient of thermal expansion. (See Method 4.)

B. Gage Reading Compensation Required

When piece and gage master are not at the same temperature or do not have the same coefficients of thermal expansion, the gaging error may be determined by use of formulas, graphs, or tables.

Method 3—The DoALL Formula

Limitations: This formula is adequate only when the piece and gage block build-up (gage master) are at the same temperature and when the gage block build-up (gage master) is *exactly* the same size as the piece at the time of gaging.

The DoALL Formula

A = Actual length of part at 68°F.

D = Difference between coefficients (Coefficient of thermal expansion for DoALL gage blocks is 6.4×10^{-6} in./in./ °F.)

C = Coefficient of expansion of material

T = Difference between room temperature and International Standard Temperature (68°F.).

L = Nominal Length of gage block

(1) If temperature is above 68°F.:

$A = L - (D \times T \times L)$ if C is greater than 6.4×10^{-6} in./in./ °F.

$A = L + (D \times T \times L)$ if C is less than 6.4×10^{-6} in./in./ °F.

(2) If temperature is below 68°F.:

$A = L + (D \times T \times L)$ if C is greater than 6.4×10^{-6} in./in./ °F.

$A = L - (D \times T \times L)$ if C is less than 6.4×10^{-6} in./in./ °F.

Method 4—By the formula developed by the Ford Aircraft Engine Division Process Capability Program

$$S_a = S_g + S_m[C_m(T_m - 68°) - C_p(T_p - 68°)]$$

S_a = Actual size of piece at 68°F.

S_g = Gaged piece size.

S_m = Size of master at 68°F.

C_m = Coefficient of thermal expansion of master

T_m = Temperature of master (°F.)

C_p = Coefficient of thermal expansion of piece

T_p = Temperature of piece (°F.)

This formula, and Method 2 do not give the additional gaging error due to the expansion of the difference between actual piece size at 68°F. and actual master size at 68°F. This difference is usually very small and well beyond the accuracy of most gage masters.

For example, in Fig. 3, this error is

$$\begin{aligned} &5.0 \times 10^{-6} \times [10.001 - 10.000] \times 5 \\ &= 5.0 \times 10^{-6} \times 0.001 \times 5 \\ &= 5.0 \times 10^{-6} \times 0.005 \\ &= 0.025 \times 10^{-6} \\ &= 0.000000025 \end{aligned}$$

This additional error may be safely ignored.

If perfect accuracy is desired, (and this presupposes perfect temperature measurements, perfect gage masters, and perfect gaging) the following formula, also developed by the Ford A.E.D. Process Capability Program, may be used.

$$S_a = S_g + S_m[C_m(T_m - 68°)] \div 1 + C_p(T_p - 68°)$$

Notation is the same as for the previous formula.

Method 5—Graphic Solution

Make a graph (See Fig. 3) with dimensional size plotted on the vertical axis and temperature plotted on the horizontal axis. Plot the slopes of the coefficients of thermal expansion of the piece and the master with the slope intercepts at the intersection of the actual size of the master at 68°F. on the vertical scale and at 68°F. on the horizontal scale.

To determine error compensation, plot the gage and master temperatures; the vertical distance between these two points is the gaging error compensation. If the temperatures are above 68°F., and the master has a *larger* coefficient than the piece, *add* the error compensation to the size gaged. If the temperatures are above 68°F., and the master has a *smaller* coefficient than the piece, *subtract* the error compensation from the *size gaged*.

Method 6—Make a table showing the error compensation for each combination of master and piece temperatures. (See Appendix II for typical gaging conditions and solutions.)

Analysis of Methods

The fastest and least susceptible to inspector error are the first two methods, which give correct size at time of gaging.

Method 1—Requires temperature control only.

Method 2—Requires both temperature and coefficient control.

Most other methods require the inspector to solve problems, or refer to graphs or tables, for an error compensation figure which is then added or subtracted to the size gaged.

Types of Problems Occurring in Industry

Generally problems are caused by a combination of temperature differences and differences in coefficients of thermal expansion between masters and pieces with temperature variations having the greatest effect in causing error. Further difficulties are experienced when masters are affected by changing room temperatures while pieces are controlled by coolant temperatures. This usually results in unnecessary machine adjustments. Still more difficulties frequently occur at final inspection stations where, depending upon temperature conditions, pieces which would check good at 68° may be reworked or scrapped and pieces which would be "Out-of-Process" at 68° are accepted.

Yet another problem occurs. Convection currents can vary room temperature over short distances. At final inspection stations this could mean a temperature difference between the gage master and the pieces.

The problems presented in Appendix II are moderate. Actual production problems frequently involve dimensions of 40.000 ± 0.001. The use of aluminum and magnesium with their respective coefficients of thermal expansion of approximately 12.5×10^{-6} in./in./ °F. and 14.5×10^{-6} in./°F. usually tend to increase any gaging errors. While the increasing use of gage masters of basically the same material as the pieces being inspected is an indication of the growing recognition and understanding of this type of problem, all this effort is wasted unless adequate temperature controls are enforced. Inspecting parts in a room which is called a "Cold Room" because its temperature ranges from 72°F. to 76°F. (at the same time in different locations) while the outside area temperatures are in the eighties or nineties should not be considered as adequate control.

However, once process and quality control engineering groups are taught to consider processing and gage design with respect to gaging errors caused by temperature variations, these problems will be solved on paper before gaging is bought and will not be first noticed on the production floor.

Recommendations

A. Design Control

1. Have process and quality control engineering groups analyze present and contemplated processing as to whether the combination of material coefficients of thermal expansion, dimensions, tolerances and machining conditions will produce those conditions whereby gaging error, due to temperature conditions, may be expected.
2. After providing necessary controls, "Finalize-in-Process" as many of these dimensions as possible, so that subsequent inspection is minimized.
3. Specify Inspection Instruction Sheet and Operation Process Sheet identification of these dimensions and the necessary controlled conditions and the coefficients of thermal expansion of piece and master for gaging temperature.

B. Gage Master Control in Fluctuating Temperature Areas

Masters are to be kept under coolant flow under the following conditions:

4. Each group of machines using a common gage master should have accurate thermometers indicating their individual coolant temperatures. Machine with master must be at 67°F. to 69°F. and other machines be within 1°F. of master temperature.
5. Masters must be positioned so that they are "free-to-move". (Do *not* wedge master into coolant tray).
6. Protect masters from "mist" or "spray" from machining operations by installing aerator spray nozzles on coolant nozzles which cover gage masters. The rate of evaporation of "mist" is much greater than a solid stream of coolant and the cooling effect of this "mist" can induce a temperature change along the master of as much as 4°F.

C. Gage Control

7. Calibrate gage to master *immediately* before each inspection. This is especially important when shop temperatures (and therefore gage temperatures) are changing.

D. Piece Control

8. While machining, flood as much of piece as possible with coolant. After machining is completed flood piece with coolant for as long as required, dependent on the thermal conductivity characteristics of the piece. Flooding should be done at a low R.P.M. Inspect immediately afterwards.

Even if the above conditions are fulfilled no further inspection of the piece out of the machine will be possible except as follows:

(a)—Piece and gage master both at 68°F. *or*

(b)—Actual size calculated by use of formula. (Temperatures of piece and master during gaging must be measured accurately. See Appendix II.)

Since both of these methods are expensive and time consuming:

9. Make gage masters of material with same coefficients of thermal expansion as piece parts. Then the only temperature condition necessary for accurate gaging will be that the piece and master are at the *same* temperature.
   With gage masters made as recommended above, refrigerated coolant controls would not be necessary. However, refrigerated or not, the coolant on all machines using a common master must be at the same temperature; therefore
10. Install a central coolant pump servicing each group of machines using the same master.

Institution of the above recommendations will yield the conditions necessary for accurate gaging without additional computation.

Appendix I

"One of the most frequently measured physical properties of materials is thermal expansion. Virtually all materials undergo a change of dimensions when they are heated or cooled. . . . Allowances for differences in thermal expansion of various materials must be made in many scientific and industrial applications."

Metals Handbook, **1948 Ed., p. 168**

The 'coefficient' of thermal expansion of material is the amount an inch of that material will expand for a one degree change in temperature.

All temperatures used in this article will be expressed in degrees Fahrenheit and the coefficients used are good for temperature ranges of 60°F. to 100°F.

Coefficients of thermal expansion are generally non-linear and change appreciably over large temperature ranges.

"Errors Caused by Variations in Temperature—An error may be introduced by variations in temperature of work and gages and may assume serious proportions, especially when great lengths are considered. For example, a 10-in. standard end rod having a coefficient of expansion of 0.0000064 per °F. per inch would show

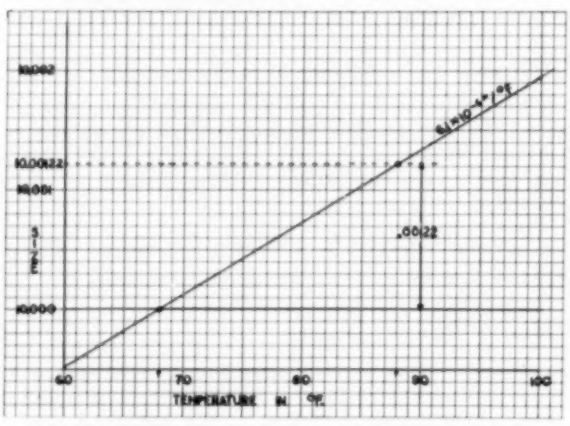

Figure 1—Specific Gage Master Correction Curve (Actual Size at 68°F = 10.0)

a change of approximately 0.00013 in. for each 2°F. variation in temperature. Frequently such an error is increased by lack of definite knowledge of the particular coefficient of expansion."

Tool Engineers Handbook, **1949, p. 1288**

Computation for the above problem is as follows:

$$\begin{aligned} & 6.4 \times 10^{-6} \text{ in.} \times 10 \text{ in.} \times 2°\text{F.} \\ &= 6.4 \times 10^{-6} \times 20 \\ &= 128.0 \times 10^{-6} \\ &= 0.000128 \\ &= 0.00013 \end{aligned}$$

It is the practice of some gage manufacturers to stamp "20°C." on their vernier calipers, indicating accuracy at that temperature only. (20°C. = 68°F.; 68°F. is the international standard at which measurements may be accurately made without 'compensation'.)

Appendix II

A series of examples will be given to illustrate the effects of temperature variation on materials. Each example in itself is a simple problem. However, gaging problems are usually caused by a *combination* of simple problems and therefore must be considered as complex problems.

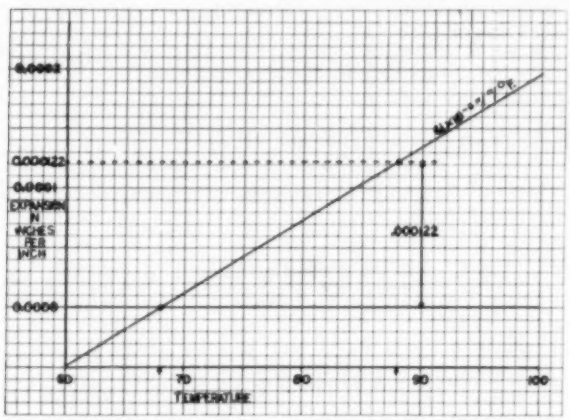

Figure 2—General Gage Master Correction Curve

Example 1

The coefficient of thermal expansion of some gage masters is

$$6.1 \times 10^{-6} \text{ in./in./ °F.}$$

To determine the actual size of a gage master at 88°F. when the actual size at 68°F. is 10.0 in. the following formula is used: *

$$\text{Size (at 88°)} = \text{Size (at 68°)} \times [1 + \text{Coefficient of Expansion (Temperature} - 68°)]$$

or

$$\begin{aligned} \text{Size (at 88°)} &= 10[1 + 6.1 \times 10^{-6}(88 - 68)] \\ &= 10[1 + 6.1 \times 10^{-6}(20)] \\ &= 10[1 + 122.0 \times 10^{-6}] \\ &= 10[1 + 0.000122] \\ &= 10 + 0.00122 \\ &= 10.00122 \end{aligned}$$

*The use of a horizontal bar over the last digit of a number is used to indicate that the digit repeats. Example: $10.0 = 10.000000000\ldots$

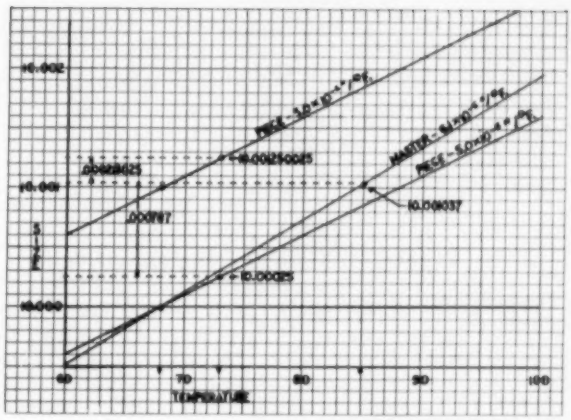

Figure 3—Graphic Solution

Problems of this sort, where the actual size at 68° is known and the size at other temperatures is unknown, may be solved graphically as shown in Fig. 1. Accuracy is limited by the scale on which the graph is made. A graph of this sort, where actual size is expressed, is valid only for that dimension but makes the explanation of this general type of problem simpler. Graphs are usually made so that the vertical axis expresses change in "inches per inch" which must then be multiplied by the length (at 68°) of the specific part being investigated. Figure 2 shows the problem in Example 2 so plotted.

Example 2

Temperature conditions alone may vary as follows:

Condition	Master	Piece
1	68°F.	68°F.
2	68	68 + X°
3	68 + X°	68
4	68 + X°	68 + X°
5	68 + X°	68 + Y°

and coefficients of thermal expansion of master and piece may be alike or unlike.

In the following problems we will stipulate that the length of the gage master and of the piece part at 68°F. is 10.0 in.

Statistics is for the Birds?

Dr. J. Stuart Hunter was in the midst of expounding on response surface methodology at a recent course sponsored by the Chemical Division of ASQC in Chicago when he was confronted by a somewhat unusual situation. A pigeon, standing on a window sill outside, apparently heard Stu's reference to mother nature through the partially open window and decided to step in and investigate. Once inside, the pigeon made a quick aerial survey of the class and then settled quietly at the back of the room.

Stu did not appear at all perturbed about the matter, possibly thinking that as long as statistics have universal applicability why not statistics for the birds, too. The pigeon was quite attentive for some time, but when Stu took off on higher order models, the pigeon decided it was time for him to take off, too, and made a neat exit through the one window which happened to be open from the top.

Condition 1

	Master	*Piece*
Temperature	68°	68°
Coefficient	Any	Any
Size at 68°	10.0	$10.\bar{0}$
Actual Size at "T"	10.0	10.0
Size gaged		$10.\bar{0}$
Error		None

Condition 2

	Master	*Piece*
Temperature	68°	73°
Coefficient	Any	Any—Assume 6.1×10^{-6} in./in./ °F
Size at 68°	$10.\bar{0}$	$10.\bar{0}$
Actual Size at "T"	$10.\bar{0}$	10.000305
Size gaged		10.000305
Error		0.000305

Solution:

$$6.1 \times 10^{-6} \times 10 \times 5$$
$$= 6.1 \times 10^{-6} \times 50$$
$$= 305.0 \times 10^{-6}$$
$$= 0.000305$$

Note: The solutions to the problems in Conditions 2, 4B, 5A, and 5B are possible only when we know the length of the piece at 68°F. In actual gaging practice this is the solution we are trying to determine. Therefore, these calculations *cannot* be used in actual gaging problems where the length of the piece at 68°F. is unknown. The examples are for the purpose of illustrating what happens under certain sets of conditions.

Condition 3

	Master	*Piece*
Temperature	73°	68°
Coefficient	Any—Assume 6.1×10^{-6} in./in./ °F	Any
Size at 68°	$10.\bar{0}$	$10.\bar{0}$
Actual Size at "T"	10.000305	$10.\bar{0}$
Size gaged		9.999695
Error		−0.000305

Solution:

$$6.1 \times 10^{-6} \times 10 \times 5$$
$$= 6.1 \times 10^{-6} \times 50$$
$$= 305.0 \times 10^{-6}$$
$$= 0.000305$$

Condition 4A

	Master	*Piece*
Temperature	73°	73°
Coefficient	Any	Same as master
Size at 68°	$10.\bar{0}$	$10.\bar{0}$
Actual size at "T"	Same as piece	Same as master
Size gaged		$10.\bar{0}$
Error		*None*

Condition 4B

	Master	*Piece*
Temperature	73°	78°
Coefficient	6.1×10^{-6}	5.0×10^{-6}
Size at 68°	$10.\bar{0}$	10.0
Actual size at "T"	10.000305	10.000250
Size gaged		9.999945
Error		−0.000055

Solution:

$$6.1 \times 10^{-6} \times 10 \times 5 = 0.000305$$
$$5.0 \times 10^{-6} \times 10 \times 5 = 0.000250$$
$$0.000305 - 0.000250 = 0.000055$$
$$10.\bar{0} - 0.000055 = 9.999945$$

An interesting point in this example occurs because the master has a greater coefficient than the piece part. When both are cooled to 68°F, the piece *increases in size relative to the master.*

Condition 5A

	Master	*Piece*
Temperature	73°	85°
Coefficient	6.1	6.1
Size at 68°	$10.\bar{0}$	$10.\bar{0}$
Actual size at "T"	10.000305	10.001037
Size gaged		10.000732
Error		0.000732

Solution:

$$6.1 \times 10^{-6} \times 10 \times 5 = 0.000305$$
$$6.1 \times 10^{-6} \times 10 \times 17 = 0.001037$$
$$10.001037 - 10.000305 = 0.000732$$
$$10.\bar{0} + 0.000732 = 10.000732$$

Condition 5B

	Master	*Piece*
Temperature	73°	85°
Coefficient	6.1	5.0
Size at 68°	$10.\bar{0}$	$10.\bar{0}$
Actual size at "T"	10.000305	10.000850
Size gaged		10.000545
Error		0.000545

Solution:

$$6.1 \times 10^{-6} \times 10 \times 5 = 0.000305$$
$$5.0 \times 10^{-6} \times 10 \times 17 = 0.000850$$
$$10.000850 - 10.000305 = 0.000545$$
$$10.\bar{0} + 0.000545 = 10.000545$$

Example 3

Problems such as those in Condition 5B are a common occurrence. Let us consider such a complex problem stipulating that the actual size of the gage master and piece at 68° F. is $10.\bar{0}$. We will use a Federal Master and a titanium piece with the master at room temperature and check the piece immediately after machining, while it is still affected by coolant temperature.

	Master	*Piece*
Temperature	85°	73°
Coefficient	6.1	5.0
Size at 68°	$10.\bar{0}$	10.0
Actual size at "T"	10.001037	10.000250
Size gaged		9.999213
Error		−0.000787

Solution:

$$6.1 \times 10^{-6} \times 10 \times 17 = 0.001037$$
$$5.0 \times 10^{-6} \times 10 \times 5 = 0.000250$$
$$10.001037 - 10.000250 = 0.000787$$
$$10.\overline{0} - 0.000787 = 9.999213$$

Let us now consider the previous problem changing only the actual size of the piece to $10.0010\overline{0}$ at 68°F. and plot both problems as shown in Fig. 3.

	Master	*Piece*
Temperature	85°	73°
Coefficient	6.1	5.0
Size at 68°	10.0	$10.0010\overline{0}$
Actual size at "T"	10.001037	10.001250025
Size gaged		10.000213025
Error		−0.000786995

Solution:

$$6.1 \times 10^{-6} \times 10 \times 17 = 0.001037$$
$$5.0 \times 10^{-6} \times 10.001 \times 5 = 0.000250025$$
$$10.001250025 - 10.001037 = 0.000213025$$
$$10.001 - 0.000213025 = 10.000786995$$

Acknowledgements

Acknowledgment is made to the following organizations for permission to use copyrighted material:

American Society of Metals

American Society of Tool Engineers

The DoALL Company

I am specifically indebted to Mr. John A. Harrington, Metrologist for The DoALL Company for his suggestions; and to Mr. Grant Donegan, Senior Analyst of the Ford A.E.D. Process Capabilty Program for the development of one of the formulas used in this article.

SUPERVISOR'S CIRCLE

PAUL A. ROBERT, *Editor*

Precision Products Co. of Cincinnati, Box 130, Norwood 12, Ohio

Fluoroscoping of Aluminum and Magnesium Castings

C. R. McCHESNEE

S. GOODMAN

Fluoroscoping of aluminum and magnesium castings for flaws was recommended as a time and money saving method by Chance Vought Aircraft after a 20-month trial of a new Navy fluoroscope.

The high intensity fluoroscope, developed by Naval Ordnance Laboratory at White Oak, Maryland for the Bureau of Aeronautics, was loaned to Chance Vought for an extended field test of its capacity to detect casting defects. For most cases, fluoroscopy was recommended over more expensive X-ray inspections.

Approximately 2000 light alloy castings were examined on the fluoroscope's viewing screen during the program conducted by the company's quality control department. Among them were a number of parts found defective after X-ray inspection had been completed.

In a report on results of the field test, C. R. McChesnee, quality control metallurgical engineer, recommended that fluoroscopy be substituted for radiography in examining castings procured as Class IA, MIL-C-6021. He suggested that X-ray examination would be necessary only on a sampling basis on such castings. For castings procured as Class IB, 100 percent fluoroscopy was recommended with no X-raying necessary.

Editor's Comments

Inspection personnel concerned with the X-ray examination of aluminum and magnesium castings will be pleased to know that the Quality Control Staff at Chance Vought Aircraft in Dallas, Texas has come up with some interesting results using fluoroscopy.

The author of a report QCR 382 entitled, "Report on Field Evaluation of the Naval Ordnance Laboratory Multi-Purpose Fluoroscope" has indicated that he has available a limited supply of this report which he will make available to any of our membership who are vitally interested in this field of inspection.

Two X-ray tubes were used in the fluoroscope machine during the tests, a 900 KVP-MA and a special high power 4000 KVP-MA tube. Chance Vought has procured a beryllium window tube for further evaluation to see if micro-shrinkage can be readily detected with it.

The Navy fluoroscope provided for castings to be placed inside a large plastic "bubble" with toy rubber balloons around it to hold it in position for inspection. The bubble with the casting enclosed can then be rotated on any axis whereas X-ray photography usually is done in two planes.

The cost of fluoroscopy is considerably less, the survey found. McChesnee cited four castings which were inspected by both methods. One cost $0.16 to inspect by fluoroscope and $0.80 by the X-ray method, a second $0.14 and $1.20, a third $0.14 and $0.80, and the fourth, $0.18 and $1.96.

The report said that fluoroscopy would probably be far superior to X-ray inspection for stainless steel brazed assemblies. Also, during the evaluation 150 aircraft pitot tubes were fluoroscope inspected inside their original cardboard cartons. Searching for sealant contamination of internal chambers in the pitot tubes, the inspector was able to spot imperfections easily.

Fluoroscopy lends itself well to quick inspection of weld beads in aluminum and magnesium. Cracks, undercutting, inclusions, and gas holes were easily detected.

Using the high power tube, grade II micro-shrinkage in magnesium and grade II gas porosity in aluminum could be detected in thin sections less than 0.5 inch. However, positive grading was difficult. For thicker sections, micro-shrinkage and gas porosity were more difficult to detect and grade.

In some cases shrinkage cracks, detected by X-ray, occurred in areas of micro-shrinkage. Inclusions that were denser than magnesium were easily detected. Sand inclusions which are occasionally missed in X-ray inspection because they are white on the film were easily detected since they are black on the fluoroscope screen, the report said.

What's New?

ROY A. WYLIE, *Editor*

When inquiring about "What's New?" items, please mention INDUSTRIAL QUALITY CONTROL

A Thread Ring Gage Reconditioning Kit for the salvaging of worn thread ring gages has been introduced by **Almeda Gage Co.**, 10851 Capital Avenue, Oak Park 37, Mich. This lapping kit, which consists of a go and no go thread lap and 600 grit lapping compound, is to be used in reconditioning worn thread ring gages which still have useful life but will not set properly on the setting plug because of taper or bellmouth from wear on the first threads. The use of this kit will correct this condition and restore the minor diameter of the ring to the correct relation with the pitch diameter. Of particular interest to users of thread ring gages for the checking of plated parts, is the ability to remove minor nicks or scratches and clear the ring of foreign matter which may have become wedged in the root of the threads.

★ ★ ★

Allegany Instrument Co., Inc., 1091 Wills Mountain, Cumberland, Md. has developed the Model 101-5A Igniter Circuit Tester to safely and accurately pre-flight or production check igniters used in solid propellant rockets. This device is a portable precision ohmmeter which limits the current through the igniter under test to 5 ma., which is a small percentage of the minimum current necessary to fire most squibs, (or electrical matches), used in igniters. Portability and safety are combined with accuracy of ± 0.01 ohm in the 0 to 5 ohm range, and ± 0.02 ohm in the 5 to 30 ohm range. Such accuracy has proved very successful in preventing missfires caused by igniter failure. The 101-5A has been approved by the Safety Engineer at the U. S. Navy Office of Chief of Ordnance and has become standard with the U. S. Army Field Services Division. The instrument is used to

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★ ★ ★

A new torque checking fixture, model TCF100 has been announced by the **P. A. Sturtevant Co.**, Addison, Ill. This new fixture is universal in nature and is designed to use torque wrenches ranging from 0 to 80 inch-grams up to and including 0 to 100 inch-pounds. Torque wrenches may be interchanged instantaneously giving the fixture an exceptionally wide range. The spindle is carried on selected instrument bearings and each torque checking fixture is inspected for torsional resistance before shipment. One of the many applications for which this new fixture is intended is the checking and setting of thread ring gages. This new fixture now permits the thread ring gage manufacturer or user to adjust and reset each ring gage with unskilled personnel, uniformly, in accordance with a preestablished table of torque values. The variations in tightness of ring thread gages on master plugs due to differences in feel can be eliminated through the use of this fixture. The torque testing fixture may also be used for testing small clutch mechanisms, electrical contacts, torsion springs, and other delicate parts and mechanisms.

★ ★ ★

The AccuRay Individual Container Fill Inspection and Rejection System has been announced by **Industrial Nucleonics Corp.**, 1205 Chesapeake Avenue, Columbus 12, Ohio. The completely automatic equipment accurately measures the height of filled material in individual tin cans or other containers moving on a conveyor line, then actuates a rejection device to remove from the line any container in which the fill height does not conform to specifications. The system may be installed on the line either before or after capping operations. Applied to a conveyor line on which liquids are being processed, the new system maintains an accuracy within ± 1/64 inch of target fill level in each container. The system is sensitive to this narrow band of tolerance even at machine speeds of 1,000 containers per minute. When utilized with lines processing dry products, such as cereals, accuracy tolerances are dependent upon uniformity of package composition and degree of horizontal level maintained by solids in the package. The system combines two principal components—a measuring head and a control unit. The meas-

Third Annual Paperwork Simplification Conference

A five-day intensive course in paperwork improvement will be conducted at the University of Dayton on Nov. 10-14.

The course is under the direction of Ben S. Graham, a senior member of ASQC. Mr. Graham is well known as a lecturer at many work simplification conferences as well as a lecturer for business and management groups from coast to coast and Canada. In addition, many of his articles on work simplification and management methods have been published.

For further information write to University of Dayton, 300 College Park Ave., Dayton 9, Ohio.

uring head incorporates a long-lived isotope energy source and detector. Containers to be inspected pass under the measuring head, and small changes in individual fill height produce variations in the amount of energy passing from the isotope source to the detector. These energy variations are translated into corresponding voltages by the detector and fed into the control unit. The control unit houses circuits which measure the voltage received from the detector and which generate a reject signal whenever the incoming voltage violates pre-set limits. The reject signal then energizes mechanical or pneumatic devices to remove the improperly filled cans from the conveyor line. The AccuRay System is applicable to processes involving containers of many different shapes and sizes found in food producing plants, breweries, the petroleum industry, chemical packaging, paint and spray production, etc.

★ ★ ★

A new development in threaded precision plug gages has been announced by **Spence Industries**, 6910 Chase Road, Dearborn, Mich. Called Jo-Plugs, these new gages simplify inspection and set-up procedures for checking the dimensional accuracy of threaded hole centers. The gage consists of a threaded plug base and an upper spindle called a Jo-spindle. Jo-spindles act as a constant throughout the entire range of plug sizes and are a uniform 0.200 inches in diameter. To check center distances, proper size Jo-Plugs are screwed into the holes, allowing the Jo-spindle to act as reference measuring points. The checker then has only to measure the distance between Jo-spindles, and add the constant 0.200 to obtain the distance between centers, within a tolerance of −0.00015. Jo-Plugs are made of hardened Graphmo tool steel and are precision ground to assure a square, flat seat. They are available in boxed sets in thread sizes ranging from #4 to 1-inch, National fine or coarse thread or special thread forms.

Optical comparator layouts of greater than average accuracy may now be efficiently produced on the new Model 14-A Scribing Machine introduced by **Optical Gaging Products, Inc.**, 26 Forbes Street, Rochester 11, N. Y. The new Scribing Machine is engineered for accuracy in the order of 0.001 inches or better, yet combines extreme rugged construction with precision. It features a free floating table and a scribe carrier to speed layout work. The table area of the machine accommodates glass or plastic chart materials up to 14 inches in diameter or 11 × 14 inches rectangular. With the use of an accessory plotting microscope the Scribing Machine is converted into a precision layout checker.

New Literature Available

Moisture Register Co., P.O. Box 910, Alhambra, Calif. has made available literature on the woodworking industry's first transistorized moisture indicating instrument. The instrument weighs less than 2 lbs. and will make 100,000 tests without battery replacement. Ranges are 6-13 percent, 12-21 percent, 20-70 percent. A retractable, telephone type, coiled cord connects the electrode to the instrument case by means of a plug-in fitting.

A new, 12-gage catalog "D" on their expanded line of "Em-re" dial indicators is now available from Petz-Emery Inc., Pleasant Valley, N. Y. The new catalog describes and illustrates the complete "Em-re" line covering all four A.G.D. groups.

A supplementary list of publications of the National Bureau of Standards, July 1, 1947, to June 30, 1957 was issued May 14, 1958 by the Superintendent of Documents,

NOMINATIONS FOR THE 1957-1958 BRUMBAUGH AWARD

In accordance with the provisions governing the Brumbaugh Award, nominations by individual members of ASQC are requested in order to assist the Brumbaugh Award Committee in making its selection. Below is a ballot for your use. Please fill in the ballot and *mail it now.*

In making your selection, please keep in mind that you are to choose the article published in *Industrial Quality Control* that you judge to have made the greatest contribution to the development of industrial applications of Quality Control.

Send your ballot to Cuyler J. Hawkes, Eastman Kodak Company, Apparatus and Optical Division, 400 Plymouth Ave. N., Rochester 4, New York. All Ballots received up to Nov. 1, 1958 will be accepted.

I recommend that the article written by

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and published in the ..... issue

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be awarded the 1957-1958 Brumbaugh Award.

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(signed)

The articles which are eligible for this year's award are those that appeared in Volume XIV—July 1957-June 1958.

U. S. Government Printing Office, Washington 25, D. C. Price for the 373 page list is $1.50. The National Bureau of Standards publications listed in this supplement include Applied Mathematics Series, Building Materials and Structural Reports, Circulars, Handbooks, Research Papers, and Miscellaneous Publications. The catalog gives a brief abstract of each paper, and also contains author and subject indexes. The procedures for purchasing the publications are outlined, and a list of depository libraries throughout the United States is included. These libraries receive certain selected publications series of the Bureau.

Proving ring specifications and accessories are listed in a new four-page, two color bulletin published by Morehouse Machine Co., 1742 Sixth Ave., York, Pa. General and dimensional specifications are given for all standard capacity proving rings in both the compression and compression-tension types. Each accessory is described in light of how it facilitates use of the proving ring.

How more rapid internal visual inspection of blind rivets, parts, propellers, blades, chambers, cylinders, extrusions, guns, tubes, pipe cracking towers, furnaces, bores, forgings, castings, and machined parts can be accomplished through their line of precision-made borescopes ranging in size from a few inches to more than 60 feet in length is illustrated and described in a two color folder recently published by Lenox Instrument Co., 2012 Chancellor Street, Philadelphia 3, Pa.

section briefs

ALLENTOWN-BETHLEHEM . . . The annual summer outing and clam bake was held on Aug. 16 at Heffners Picnic Grove, Trexlertown. An exceptional dinner, refreshments, and a social evening were enjoyed by 60 members, their families and guests. It was the opinion of all present that the meeting on a social level was a very pleasing experience for all concerned. Carl Furler is to be commended for the fine job he did on the picnic arrangements; a lot of people enjoyed the day as a result of his efforts.

A meeting of the executive committee, held at the home of chairman Dave Hilder, resulted in the completion of plans for presenting QC courses to members. Course 9 will cover "Sampling Inspection" and will run concurrently in Allentown and Reading. Basic QC courses will be offered in the winter and spring sessions.

BALTIMORE . . . Frank J. Cullen, program committee chairman, has been busy during the summer months making arrangements for the diversified 1958-59 program. Plans include a "ladies night" for the Oct. 21 meeting. Members are urged to make arrangements with their ladies-fair to go out and attend an exceptionally fine meeting.

Approval was given at a recent joint meeting of the General Conference Committee and the Executive & Operating Committee to have the 1960 Middle Atlantic Conference in Baltimore. W. H. MacCrehan, General Conference Committee Chairman, completed arrangements to have the conference held Nov. 11-12, 1960 in the Lord Baltimore Hotel.

The annual one-day Baltimore-Washington Conference planned for 1959 has been cancelled at the request of the Washington section.

CHARLESTON . . . Section members have approved the following slate of officers submitted by the nominating committee: chairman—R. A. Remke, Westvaro; vice chairman—P. A. Rhudy, DuPont; secretary—M. A. Aitken, Union Carbide; and treasurer—S. C. Harris, American Viscose.

CORNING-ELMIRA . . . The executive committee met Aug. 5 to discuss and plan the 1958-59 program. At this meeting, it was announced that Ralph Simon of Corning Glass Works and Jack Cherry of Westinghouse Electric would serve as ASQC representatives on the Corning-Elmira Area Council of Scientific Societies. This council was recently organized to promote and stiumulate interest in science education and the scientific professions, especially in the area school systems. We extend our best wishes for successful accomplishment to both our representatives and the council.

DALLAS-FORT WORTH . . . The executive committee met on July 26 at the home of past chairman Dr. A. W. Wortham. The 1958-59 program was approved and appointments to handle section functions for the coming year were finalized.

The section's annual family outing was held at Briggs-Weaver Lodge on Grapevine Lake on Aug. 23. More than 200 members and guests attended. This was considered the most successful outing ever held by the section.

A course in basic SQC will be conducted by the section for its members starting Oct. 14. It will be held at Arlington State College.

ERIE . . . Instead of the usual schedule of ten meetings, the section will hold only five during the coming year. They will be held during September, November, January, March, and

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It is with deepest regret that the Buffalo section announces the sudden passing of Mr. Howard J. O'Connor on July 23. Mr. O'Connor had been chief statistician of the Electro Metallurgical Company. He will be greatly missed by members of the section.

SECTION CALENDAR (SEPTEMBER 25—OCTOBER 31)

SECTION	DATE	PLACE	TIME	SUBJECT	SPEAKER
Allentown-Bethlehem	Oct. 8	Hotel Traylor	8:00 pm	Electronics Production Line Experimentation	Frank Caplan, Westinghouse Electric Corp.
Baltimore	Oct. 21	Memorial Stadium	8:00	———	———
Columbus	Oct. 15	Bucyrus	5:00	Plant tour of the automated Timken Roller Bearing factory and warehouse	———
Corning-Elmira	Oct. 14	Ithaca	8:00	Design of Experiments	———
Dallas-Fort Worth	Oct. 9	Engr. Aud., Arlington State College	8:00	Management's Responsibility to Quality Control	J. Y. McClure, Convair-Fort Worth
Greater Muskegon	Oct. 14	Arlington State College	———	Basic SQC Course	———
Hamilton	Oct. 9	Spring Lake Country Club	———	President's Night	C. E. Fisher, Bell Telephone Laboratories, Inc.
Harrisburg	Oct. 16	Fischer's Hotel	8:00	Controlling the Quality of Management Decisions	Dorian Shainin, Rath & Strong, Inc.
Hartford	Oct. 1	Lancaster	6:15	Reliability	Robert Lusser, Redstone Arsenal
	Oct. 7	Club Alden	6:00	Executive Committee	———
	Oct. 21	Club Alden	6:00	Problem Workshop & Dinner Meeting	———
Memphis	Oct. 10	Memphis State University	8:00	Probability Applications to Control Charts and Statistical Tests	H. M. Truax, Atlas Powder Co.
Mid-Hudson	Oct. 7	Anchor Inn, Poughkeepsie	7:00	Quality Control Engineering Responsibilities	William J. Masser, General Electric Co.
Montreal	Oct. 8	Singer Mfg. Co., St. Johns	———	Plant Tour	———
	Oct. 25	Ecole Polytechnique		All-day Forum	———
Pittsburg	Oct. 28	Penn-Sheraton Hotel	8:00	———	———
Portland	Oct. 7	———	7:30	Basic Philosophy of Quality Control	Prof. Grant I. Butterbaugh, Univ. of Washington
Rochester	Oct. 21	Chamber of Commerce	6:15	———	———
	Oct. 21	Chamber of Commerce	6:15	———	———
St. Charles	Oct. 21	Club Arcada	5:30	Quality Control Applied to Automated Assembly Operations	W. E. Jones, Management Controls
San Antonio	Oct. 7	Hilton Hotel	7:30	Management's Responsibility to Quality Control	J. Y. McClure, Convair-Fort Worth
South Texas	Oct. 8	Ben Milam Hotel	7:00	Management's Responsibility to Quality Control	J. Y. McClure, Convair-Fort Worth
Toronto	Oct. 22	University of Toronto	8:00	Statistical Methods in Industrial Engineering	Dr. J. H. Davidson, General Electric Co.
	Oct. 22	Quality Records, Ltd.	7:30	Plant Tour	———
U. of W. Ontario	Oct. 8	Waterloo College	8:00	Time Study Views on QC	Panel Meeting with CIMA

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It is with deepest regret that the Chicago section announces the death of Mr. Eugene Welch as the result of an automobile accident. Mr. Welch was employed at Pellet Devices, Inc., Des Plaines. The sincerest sympathies of the members of the section go to his family and friends.

May. Each meeting will consist of an education period, social period, dinner, and an after dinner speaker.

GREATER MUSKEGON . . . The program committee met twice during the summer. At their meeting on Aug. 5, chairman Lawrence P. Long and his committee—John D. Welch, Jack Fortenbacher, and Lewis Brunner—culminated the 1958-59 program. Only a few minor details are left before the program for the year will be complete.

The membership committee met Aug. 7 at the home of chairman Mike Pascavis and completed plans for a very active membership program. Merrill S. Bailey, Jack H. Wiersema, and William A. Poe are members of Mike's committee.

Oct. 9 has been designated "President's Night." Society President C. E. Fisher, Bell Telephone Laboratories, Inc., will be guest speaker. The meeting will be held at the Spring Lake Country Club.

HARRISBURG . . . The executive committee has been busy this summer making plans for the 1958-59 season. Membership chairman Harry Metcalf and education chairman Jim Ramsey have active programs already underway. The program committee under George Thomas has a program outlined with several outstanding speakers whose talks will satisfy the varied interests of the entire membership.

The first meeting of the season will be held Oct. 1 at the RCA Office Bldg., Lancaster. Robert Lusser, reliability coordinator at the Redstone Arsenal, Huntsville, Ala., who is an outstanding authority on reliability, will be the guest speaker. The Lancaster section of IRE will co-sponsor this event.

HARTFORD . . . The executive committee met at the Club Alden on Aug. 5. Vice chairman Herb France presented a tentative listing of speakers and topics to be discussed at the eight meetings scheduled for the coming season. In addition to the regular dinner meetings, at least two panel meetings are to be held.

A new innovation is to be inaugurated this year. A "problem workshop" starting at 4 pm will be held prior to each regular dinner meeting. All members are encouraged to present their problems for discussion by fellow members under the guidance of a moderator.

Three educational courses in the theory and practice of SQC are to be offered. Basic, intermediate, and advanced courses are to begin in late October or early November. For further information contact educational program chairman Ken Martin, Royal McBee Corp.

LOS ANGELES . . . The recent two week intensive course held at UCLA and sponsored by the section and other professional groups was well received.

MID-HUDSON . . . William J. Masser of GE's electric engineering service staff will be the guest speaker at the Oct. 7 meeting. According to tentative plans, the 7 pm meeting will be held at the Anchor Inn, Poughkeepsie. Mr. Masser's topic will be "Quality control engineering—responsibilities and accountabilities."

Chairman Frank J. Sindelar has announced the following appointments: Carl W. Wetzel, chairman of the technical group; and William Bobalke, chairman of education.

MONTREAL . . . Section members will visit the St. John's plant of the Singer Mfg. Co. on Oct. 8 to observe their QC program in action and to tour the plant.

An all-day forum will be conducted Oct. 25 at the Ecole Polytechnique under the chairmanship of E. N. Beckett of Northern Electric Co., Ltd. The forum theme is "Solving industrial problems through better quality control." Speakers from leading Canadian industries as well as some from the United States will lead the gathering.

One of the outstanding features of the forum will be an all-day training course in the fundamentals of statistical quality control. This session will be conducted by J. O'Callaghan of the British American Oil Co. (Toronto) and W. Pukalo of the Department of National Defense, Inspection Services (Toronto).

The guest speaker at the luncheon will be newly elected Society vice president Dr. A. V. Feigenbaum of the General Electric Co. (New York) who is the author of the well-known book, "Quality Control Principles, Practice and Administration."

PITTSBURGH . . . During the summer months, various members of the section were active. Section president John Hromi of U. S. Steel Corp. gave a paper as part of a panel on statistics in industrial research at Oklahoma State University, Stillwater, Okla.

William I. Martin of Koppers Co. attended the Gordon conference on statistics in chemistry and chemical engineering held at New Hampton, N. H., under the auspices of AAAS.

Charles Pratt of Koppers Co. attended the 15th annual Rochester Institute of Technology's quality control for the chemical industries course.

PORTLAND . . . During the month of August, publicity chairman Herman Karlebach investigated the possibilities of having an ASQC booth for the Oregon Centennial which will be held in 1959 here in Portland. The cost of the exhibit and the value of the booth were taken into consideration. A report was made to the executive committee and enthusiasm is high. Mr. Conrad, section president, has since forwarded a letter to the Society's headquarters office in Milwaukee notifying them of our intentions and of the possibilities for the promulgation of ASQC—its value, its increasing capabilities, and its place in the future of America and economics. The opportunity to place ASQC and its value to the consumer before millions of people was offered to the headquarters office for their consideration and action.

The Portland section extends an open invitation to all ASQC members and their families to vacation in Oregon in 1959 and visit the exhibit.

ROCHESTER . . . The technical subgroup will hold its first meeting on Oct. 7.

The regular section meeting will take place on Oct. 21.

Speakers and topics for both meetings will be announced later.

ST. CHARLES . . . The October meeting will be held on Tuesday, the 21st, at Club Areada. Registration and a social hour will begin at 5:30 pm followed by a western style buffet dinner. At 8 W. E. Jones, Fellow of ASQC and senior partner of Management Controls of Des Plaines, will present an interesting talk on the timely subject "Quality control applied to automated assembly operations." For reservations ($2.75 for members and $3.25 for guests) contact H. Jahns, Burgess-Norton Mfg. Co.

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The Chemical Division and the Buffalo section of ASQC invite your attendance at an outstanding technical conference. If you missed the details in the August issue of *Industrial Quality Control*, get your copy out right now and look on page 10 and 35.

To the list of speakers should be added the following:

Experimental Designs—The Key to Practical Bulk Sampling Studies, Victor B. Shelburne, The Carborundum Company; *A Procedure for Settling Vendor-Consumer Product Quality Measurement Differences*, L. J. Myers, Esso Standard Oil Company.

It isn't too late to make arrangements to attend and you are assured of an outstanding welcome in the city of good neighbors. Buffalo is served by major airlines and railroads, the New York Thruway, and the Queen Elizabeth Way.

We hope to see you in Buffalo.

A 15-week lecture course in metrology (the science of precision measurement) is being sponsored by the section. The course, "Inspection Training Program," is conducted on Thursday evenings from 7:30-9:30 pm and is held in the main auditorium of the St. Charles High School. Edwin M. Pearne is the instructor. Late registrations may be obtained by contacting W. R. Fischer, General Electric Co., East Pleasant Street, DeKalb, Ill. The fee is $50 for members and $60 for non-members.

SAN ANTONIO . . . Over 115 members and guests spent a fine evening at our annual picnic on July 3. This social was held in the "Little German Beer Garden" at the Lone Star Brewery and a delicious bar-b-que chicken dinner was enjoyed by all. After dinner, installation of new section officers was held. This was followed by dancing "under the stars" on the patio. To conclude the evening's festivities, a drawing was held and three lovely attendance prizes were awarded to the winners who were David Golden, Mrs. Mary Miller Rose, and Mrs. William St. John.

SOUTH TEXAS . . . A "kickoff" meeting for the executive committee was held Aug. 20 at Champion Paper Co., Pasadena.

The new officers are: chairman—Richard M. Shappee, Aviation Instrument Mfg. Co.; vice chairman—A. R. Stark, Humble Oil & Refining Co.; secretary—Buford M. Appleman, Texas Foundries, Inc.; and treasurer—Obert L. Nordin, Thornhill-Craver Co.

TENNESSEE . . . After a long vacation your section's reporter is on the job once again! We hope to keep an up-to-date plot of our progress for you.

A rumbling and stirring has begun in the section—it's readying itself for the strenuous year ahead. At the executive meeting which started the work year off, ideas and plans were laid that indicate a busy time ahead for all. Of major importance are the short course in quality control methods and the kickoff meeting to be held in late September or early October, and the attempt at giving birth to a new section in the Kingsport-Tri-Cities area. Hubert Hill and the other fellows in that area have an impressive list of prospective members, too. Good luck!

TORONTO . . . Preparations for the 1959 QC Forum are now underway. A committee has been formed and, under the able chairmanship of S. Brodsky, much of the initial groundwork has been accomplished.

A most valuable course in quality control by means of statistical methods wil' be given at the University of Toronto commencing Monday, Oct. 8, at 7:30 pm. This course, sponsored by the section, will be comprised of 20 lectures and should appeal in particular to those requiring a sound basic knowledge of SQC.

UNIVERSITY OF WESTERN ONTARIO . . . At an executive meeting held on Aug. 13, the program for the coming year was finalized.

A joint executive meeting was held with the Hamilton section on Aug. 20 to discuss plans for the forum to be held in Hamilton in November.

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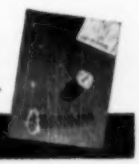

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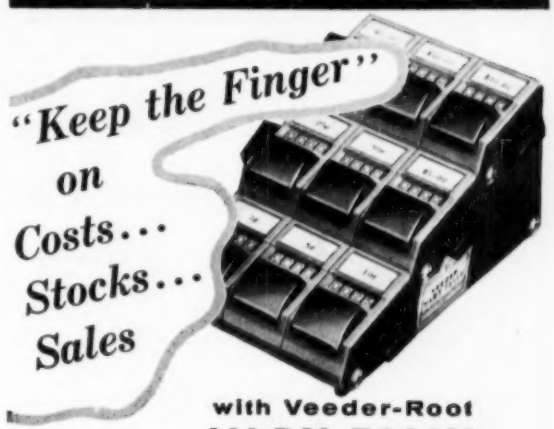

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The meeting on Oct. 8 will be a panel discussion with members from industrial engineering and quality control. The subject will be "Time study views on quality control." This will be a joint meeting with the Grand Valley Branch of the Canadian Industrial Management Association.

SIGNIFICANT DIFFERENCES

. . . Allentown-Bethlehem—G. F. Brader has been transferred from the Allentown plant to the Laureldale plant of Western Electric.

R. Schin has been appointed chairman of the professional work elements committee which is a sub committee of the special committee on professional development.

. . . Chicago—Howard Jones, one of the oldest members and officers of the section, retired from the Bell Telephone Co. to accept a professoriate appointment at the University of Chicago's School of Business under the Deanship of Dr. Allen Wallis.

William L. Lieberman, formerly of the Pentron Corp., has accepted a position with Armour & Co., meat packers. Mr. Lieberman will be active in the establishment of a new quality control department.

. . . Columbus—William F. Morgan of North American Aviation has taken a new position at Sperry Farragut Co., Division of Sperry Rand Corp., Bristol, Tenn. He will head their quality review section.

. . . Corning-Elmyra—Steve Jurnack of Sylvania Electric, Towanda, is leaving this fall to enter the Rutgers University Graduate School to begin advanced studies in SQC.

clinics, conferences, and courses

OCTOBER

. . . *1*—Regional Technical Conference, "Plastics in Packaging," Hotel Statler-Hilton, Hartford, Conn., sponsored by Society of Plastics Engineers, advanced registration fee—$9.00 for SPE members and $10.00 for non-members, contact Registration Chairman, Lawrence W. Freeman, Plax Corp., Bloomfield, Conn.

. . . ***2-3—Second Annual Conference of the Chemical Division, Hotel Statler-Hilton, Buffalo, N. Y., sponsored by ASQC; contact V. B. Shelburne, Publicity Chairman, Chemical Division Conference, The Carborundum Co., P.O. Box 337, Niagara Falls, N. Y.***

. . . ***13-15***—International Systems Meeting, Penn-Sheraton Hotel, Pittsburgh, Pa., registration fee $100, contact 1958 ISM, Parlor 70, Penn-Shearton Hotel, Pittsburgh, Pa.

. . . ***30-31***—Fourth Electronic Business Systems Conference, Olympic Hotel, Seattle, Wash., sponsored by Western Division of NMAA, contact Jack Armstrong, Publicity Chairman, Fourth Electronic Business Systems Conference, P.O. Box 134, Seattle 11, Wash.

NOVEMBER

. . . ***6-7—13th Midwest Quality Control Conference, Hotel Muehlebach, Kansas City, Mo., sponsored by ASQC, contact Publicity Chairman, Jay R. Rumberger, Westinghouse Electric Corp., 2208 E. 72nd St., Kansas City, Mo.***

. . . ***10-14***—Third Annual Paperwork Simplification Conference, University of Dayton, Dayton, Ohio, contact University of Dayton, 300 College Park Ave., Dayton 9, Ohio.

. . . ***17-18—Sixth Annual Conference of the Aircraft and Missiles Division, Biltmore Hotel, Dayton, Ohio, sponsored by ASQC, contact R. B. Van Lehn, Vernay Laboratories, Yellow Springs, Ohio.***

. . . ***17-21***—ARS Annual Meeting, Hotel Statler-Hilton, New York City, sponsored by American Rocket Society, contact Dean E. Roberts, Director of Public Relations, American Rocket Society, 500 Fifth Ave., New York 36, N. Y.

. . . ***30-Dec. 5***—ASME Annual Meeting, Hotels Statler-Hilton and Sheraton McAlpin, New York City, sponsored by American Society of Mechanical Engineers, contact L. S. Dennegar, Director of Public Relations, American Society of Mechanical Engineers, 29 West 39th St., New York 18, N. Y.

DECEMBER

. . . ***29-30***—Section M (Engineering) of 125th Annual Meeting of AAAS, Washington Statler Hotel, Washington, D. C., sponsored by American Association for the Advancement of Science, contact Secretary, Section M (Engineering), AAAS, c/o Engineers Joint Council, 29 West 39th St., New York 18, N. Y.

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106—Joplin (Dist. 13)

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Missouri Steel Castings Co.
Joplin, Mo.

Vice Chairman: Fred L. Jehle
Continental Can Co.
Coffeyville, Kans.

Secretary: James Black
Boeing Representative
Pacific Mercury Television Mfg. Corp.
Joplin, Mo.

Treasurer: Clifford J. Mattivi
Spencer Chemical Co.
Pittsburg, Kans.

Dr. Robert Bechoffer will be on sabbatical leave from Cornell University during the coming school year. Dr. Bechoffer will attend Stanford University where he will do research in theoretical statistics.

. . . Harrisburg—The section has accepted the invitation to co-sponsor the 5th district QC conference to be held Mar. 21, 1959, in Allentown, Pa.

Don Synder will take a leave of absence from his job duties with RCA to enter Rutgers University in the fall to work toward his master's degree in mathematical statistics.

. . . Hartford—Herb France has joined the Pratt & Whitney Co., Inc., West Hartford. He is on special assignment from the offices of the factory manager and the engineering manager in the general area of improving machine capabilities in the machine tool division.

. . . Los Angeles—H. D. Hill has been promoted to quality control analysis supervisor for the Autonetics Division of North American Aviation, Inc. In this new capacity, he will be responsible for the integrated product quality data which encompasses all phases of product quality from supplier to the delivered product.

. . . Montreal—Newly elected officers are: chairman—C. I. Taylor, Trans-Canada Air Lines; vice chairman—G. S. Williams, Northern Electric Co., Ltd.; secretary—S. L. Humphries, Aviation Electric, Ltd.; and treasurer—J. L. Gauthier, Sherwin-Williams of Canada, Ltd.

. . . South Texas—Buford M. Appleman has been appointed service manager at Texas Foundries, Inc., Lufkin. His new duties will encompass the quality control and production control functions.

Aircraft and Missiles Division

6th Annual Conference—November 17-18

TO ORBIT OR OBIT may be the choice and whether the latter is a consequence of the failure to achieve the former or whether the result obtains by default is in any measure of fatal concern to all of us. Certainly the initial application of the principles of ASQC preclude an OBIT by default, and the move to focus these principles for defense through the facility of an Aircraft and Missiles Division does much to diminish or eliminate the possible demise by failure.

ASQC growth has been generated through problems first of quality and then reliability and then both. The dynamics of these problems spawned diffusion of effort, then concentration, and thence divisions—and now changes within divisions. The recent change in May from the title of the Aircraft Division to the new form Aircraft and Missiles Division reflects the trend.

Problems usually precede their focus. The significance of this change is identified in the title. For the first time since the advent of the space age, those in and out of ASQC with related quality and reliability problems can identify (with precision or empathy but for certain) with assurance the functional areas of the Aircraft and Missiles Division.

There is not such a long, long time from May to November, and the members of the planning committee for the 6th Annual Aircraft and Missiles Division Conference, to be held Nov. 17-18 at the Biltmore Hotel in Dayton, Ohio, are well aware. The final tentative program for the conference was set on July 30. Bill Morgan of Sperry-Farraguat and R. C. Draudt of North American Aviation have spearheaded the composition of a program which is appropriate for the division name change as well as for the orbital era. Twenty sessions of multiple concurrent selections in two days are complemented by nationally known luncheon and banquet speakers and interim refreshment analysts. Representatives of various manufacturers, given a preview of the bill, say that it was filled for them.

The opening session is a general panel discussion "What Can Be Done to Improve Missile Quality and Reliability." The following panelists with top quality and reliability positions in government and industry set the pace and the theme: J. Riordan, Department of Defense; chairman R. J. Gutheim, Office of Guided Missiles; Capt. Levering N. Smith, USN, Special Projects Office; John J. Crowley, General Dynamics Corp.; E. J. Lancaster, Air Force Ballistics Missile Office; Lt. Col. M. L. Raines, USA, Army Ballistics Missiles Agency.

General interest, technical, and reliability orientation sessions follow. These are staffed by persons considered by the planning committee and its Division advisors to be the best in their respective topical fields.

One of the sessions is devoted to a conference innovation —contributed papers. Society members are urged to participate by contacting George Friesel, Chairman of Proceedings, Quality Control Office, Dayton Air Force Depot, Dayton, Ohio.

Exhibit space is available through J. C. Sollenberger, Airtemp Division, Chrysler Corp., Box 1041, Dayton, Ohio.

Registration and information is being handled by R. B. Van Lehn and G. Kakehashi, Vernay Laboratory, Yellow Springs, Ohio.

General conference inquiries may be directed to one of the following: (Chairman) Dr. Max Astrachan, AF Institute of Technology, Wright-Patterson AFB, Ohio; (co-chairman) William E. Smith, Statistical Quality Control, The National Cash Register Co., Dayton 9, Ohio; (secretary) Capt. Kenneth L. Jackson, USAF, AF Institute of Technology, Wright-Patterson AFB, Ohio; or (treasurer) James M. Cogar, Airtemp Division, Chrysler Corp., Box 1041, Dayton, Ohio.

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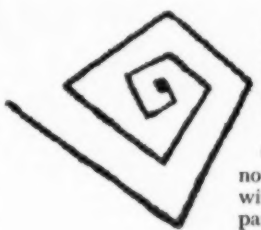

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BOOK REVIEWS

W. D. Baten, Editor

26 University Drive, East Lansing, Mich.

STATISTICAL MANUAL by Edwin Crow, Frances A. Davis, and Margaret W. Maxfield, Navord Report 3369, U. S. Ordnance Test Station, China Lake, Calif., 1955 (available from Office of Technical Service, U. S. Department of Commerce, Washington 25, D. C.), xvii plus 288 pages, price $6.00. Reviewed by W. D. Baten, Michigan State University.

This manual contains material found in some of the newer statistical texts such as ideas about measures of central tendency, measures of dispersion, various distributions, and tests concerning means, standard deviations, percentages, goodness of fit, normality, and regression coefficients under various conditions. It also presents information pertaining to fiducial limits, power of a test, determination of sample size, sign tests, relations of means and variances, Chi-Square, runs, transformations for obtaining normality, sensitivity, analysis of variance, tests for homogeneity of variances, linear, multiple and non-linear regression, correlation, reliability, confidence intervals for predicted values, quality control, orthogonal polynomials and acceptance sampling.

There are many illustrations that show how to apply statistical theory. There are 21 valuable tables, several of which do not appear in most textbooks on statistics such as critical values for the M Distribution for testing the null hypothesis that k populations have the same variance, critical values for the sign tests, critical values for runs, critical values for tests using the range, for testing whether a trend of means is real, orthogonal polynomials, a table for indicating when extreme measurements may be discarded, constants for a sampling plan with OC curves through 2 points, tables of log $1 - \beta/\alpha$ and log $1 - \alpha/\beta$, confidence limits for a proportion.

The manual contains 11 charts about probabilities of shots falling in certain 2 dimensional places, confidence belts for proportions, OC curves, number of degrees of freedom required to estimate the standard deviation within p percent of its true value, number of degrees of freedom in each sample required to estimate σ_1/σ_2 within p percent of the true value and confidence belts for the correlation coefficient.

This is a book that one will like to have on his desk for quick reference.

TABLES OF THE ERROR FUNCTIONS AND ITS FIRST TWENTY DERIVATIVES by the Staff of the Computation Laboratory of Harvard University, Harvard University Press, 1952, xxvii plus 276 pages, price $2.50. Reviewed by W. D. Baten, Michigan State University.

The introduction contains mathematical developments of formulas used in obtaining the tables and how the table-values can be used in practical problems. The tables contain the heights of the normal curve at x, the areas "under" the normal curve from 0 to x, and the first ten derivatives at x for $x = 0 - 8.236$. They also contain the derivatives of and the normal curve of order eleven through fifteen for arguments $x = 0.000$

(Concluded on page 40)

(0.002) 9.610 and its derivatives of order sixteen through twenty for x = 0.000 (0.002) 10.902. All of the table values are given to six decimal places and are easy to read.

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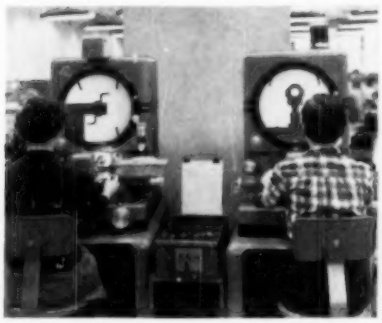
See how optical gaging solves 4 basic inspection problems faster... at less cost



(1) RECEIVING: With optical gaging you get *immediate* checks on tolerance for incoming precision parts. One glance tells whether parts are to your specification. For example:

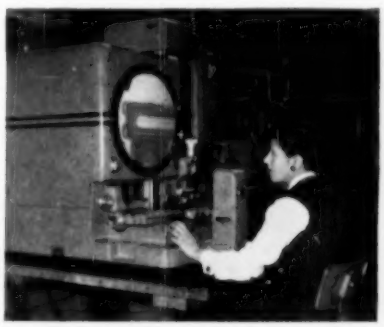
Inspectors at the *Allen-Bradley Company*, makers of electrical equipment, use Kodak Contour Projectors for fast, accurate inspection of incoming precision parts. They check *more than 400 different items*, most with multiple dimensions, and sample size of 35 or more pieces. Tolerances are held to .001". Since optical gaging permits checking several dimensions at once, Allen-Bradley has drastically cut inspection time. Parts are quickly cleared for production; quality control is better.

(2) ASSEMBLY: Mass producing your product may require fast yet accurate inspection of precision component assemblies. Here's how one manufacturer solved the problem:

Magnetron Beam Switching Tube, produced by *Electronic Tube Division, Burroughs Corporation*, has 21 elements which fit into mica holding-wafers at top and bottom. The elements must be lined up to within .002" of specifications. The problem was to do this complex inspection job *fast enough to keep up with assembly speed* in mass production. With a Kodak Contour Projector the inspector can easily match top assembly speeds while maintaining the required specifications.

(3) FINAL INSPECTION: You can inspect a great variety of finished parts quickly with the Kodak Contour Projector—and cut costs, too.

In one instance, a great variety of component parts for various manufacturers posed a serious inspection problem for *Auburn Plastics, Inc.*, a custom molder. The firm formerly used mechanical gages in large numbers to make necessary quality control checks. A Kodak Contour Projector eliminated the expense of buying mechanical gages (savings amounted to $5,000 in one instance). Now operators can inspect at a glance finished components—gage angles, radii, holes, and other dimensions—with an accuracy that meets close tolerances.



(4) PRODUCTION: Optical gaging gives you accurate, fast inspection of tools and dies during use in production.

For example, at *Stromberg-Carlson*, a Division of General Dynamics Corp., die life presented a complex gaging problem. Checking by conventional gaging methods was cumbersome, time-consuming, and inaccurate. Optical gaging of piece parts with a Kodak Contour Projector now provides a quick, accurate check of die wear during production. A typical example concerns a die which stamps out relay lever arms. The 35 dimensions of the lever arm are optically checked in 1/3 the time of other gaging methods.

Optical gaging with the Kodak Contour Projector saves time because you can check many dimensions at a glance. Saves you money, too, because one projector does a wide variety of gaging jobs. Changing from one type of part to another is a simple matter of changing your chart-gages on the screen and your fixtures.

Whatever your inspection or measuring problem may be, there's a Kodak Contour Projector to do the job—from the compact bench-type Model 8 to the big Model 30 with its 30-inch screen and large part capacity.

For additional details, send for the new illustrated booklet "Kodak Contour Projectors." Write to:

Apparatus and Optical Division

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the KODAK CONTOUR PROJECTOR

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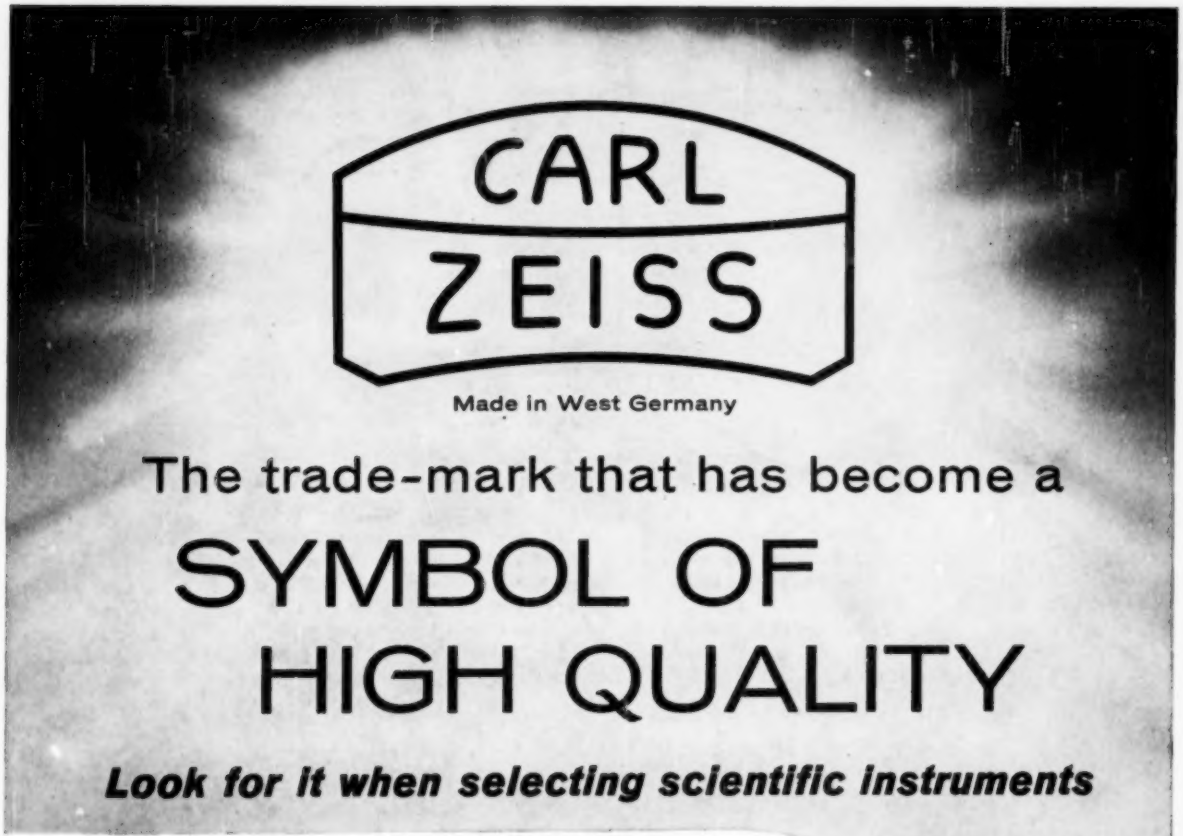

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